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ORIGINAL ARTICLES.

Syntexis and Differentiation.

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PETROGENIC problems concern the processes and effects of adding to magma, or subtracting from it, rock-forming substance in general. Increment or loss of silica alone entails relatively simple mineralogical consequences. The more intricate problems concern the addition of associated material (notably alumina, the RO-oxides, alkalies, and fluxes) in varying relative proportions, and at any stage in the evolution of rest-magma. These additions tend either to promote, counter, or otherwise modify the prevailing trend of differentiation in magma thus augmented.

In numerous instances, both the processes and effects of such addition have been described and, in a variety of ways, checked. Direct field-evidence is gained largely from near-surface exposures, where the effects of localized reaction between magma and country-rock are often striking enough to afford valuable hints concerning the processes and extent of assimilation possible (Daly, 1914)[1] under the TP-conditions prevailing at greater depths. But contamination or syntexis verifiable in near-surface exposures is admittedly on a smaller scale than that postulated by Daly, on whose hypothesis *syntectic magma could attain to approximate homogeneity, and even differentiate, prior to its ascent to higher levels of the earth's crust.*

"Field" evidence not the sole criterion of syntexis.

A wealth of descriptive detail is on record concerning xenolith-reconstitution, abnormal mineralogy, peculiarities of microstructure, etc., which have afforded clues to hybridization or contamination in particular cases; the list needs no recapitulation here. *But a*

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[1] Names and dates in parentheses refer to bibliography at end.

substantial mass of acid differentiate from syntectic magma packed with xenoliths may contain no recognizable xenoliths at all (e.g. the " white granite " of Ballachulish—described by Dr. F. Walker, 1924), though, as in the case cited, descent from such magma may be demonstrable on field-evidence alone, or by a comparative study of serial rock-specimens.

The syntectic origin of many acid and intermediate rock-types has long been debated, and in several cases established. " If there were not so many slates, there would not be so many norites " is a conclusion drawn by Professor H. H. Read (1931, 453) on convincing field-evidence (see also Bowen, 1928, 214). Hornblende-gabbros are also types debated (Daly, 1914, p. 319). The problem of the andesites is specially complex : the genesis of the mica- and hornblende-andesites is one of " extreme delicacy " (Daly, 1914, 380) ; that of the more acid andesites is " identical with that of some diorites " (Daly, 381). In fact, few rock-types above the ultra-basic field have escaped debate concerning origin—as syntectics, or as differentiates from such mixtures. Controversy will continue until the issues, in adequate number, have been disposed of by trial on the evidence of fact. The strongest evidence is field-fact ; but the really serious and difficult problem arises when a syntectic or palingenetic origin is asserted, or suspected, for types such as hornblende-gabbro, quartz-monzonite, tonalite, diorite, hornblende-biotite-syenite, granodiorite, and granites in general—which may contain no xenoliths, and may be essentially uniform in both texture and mineral composition.

Evidence based on consanguinity.

The term " consanguinity ", as used by Daly, covers not only those characters inherited from some ultimate parental (or primary) magma but also endowments from crustal rocks—by syntexis of the latter with primary magma or its differentiates. Syntexis, according to Daly, occurs mainly at depth, and engages crustal rocks not directly determinable : even xenoliths may be wanting or so profoundly modified that, examined in the light of our present knowledge concerning reciprocal exchanges between magma and xenoliths, they afford little or no index to their original identity.

A logical approach to this difficult depth-problem is the study of consanguinity in its twofold aspect, on the modest scale afforded by near-surface assimilation-phenomena. Both sedimentary and metamorphic rocks invite geochemical study on a more liberal and intensive scale than has hitherto been regarded as necessary. Minor constituents in particular and their host-minerals (mafic or felsic) could afford valuable criteria applicable to genetic questions. To plead for more than this may be " to cry for the moon " ; yet a closer correlation of bulk-composition with metamorphic " isograd " status (as advocated by Professor C. E. Tilley, 1924)—the specific minerals present, their relative proportions, grade-size, and textural rôles, would provide both facts and principles applicable to the interpretation of xenoliths, contamination effects, and hybrids.

The incorporation of shale (or sandstone) by magma is something more than the simple addition of alumina (or silica) :—

Clarke's " av. shale " for example (1916, 28), contains more than 54 per cent of substance which, computed to a percentage norm-basis, represents orthoclase 34 per cent, albite 12 per cent, basifying constituents 24 per cent, and only 19 per cent of unallotted alumina—together with the equivalent of 10 per cent limestone. Minor constituents such as vanadia, ceria, etc. are not usually looked for by the analyst. On the average, shales contain as much P_2O_5 as granites, and vanadium from the weathering of igneous rocks goes mostly with the clays (Jost, 1932). Carter (1931) has described vanadiferous clays and marls from South Devon, and McClintock comments on the possible relationship of apatite to xenoliths of phosphatic shales (1923, 148) in the Meldon aplite.

More than twenty years ago Hillebrand (1910, 16–27) impeached the adequacy of rock-analyses, and stressed the need for analytical data concerning " all that a mineral or rock contained ", special reference being made to the petrographer's interest in the minor constituents.

Daly's " av. sandstone " (1914, 400) contains nearly 30 per cent of substance comprising salic and femic minerals in nearly equal proportions, and four-fifths of the femic portion equates a magnesian limestone.

The incorporation of a calcareous shale (or calcareous sandstone) presents a wide range of possibilities—depending on the particular case. If limestone tends to desilicate magma and promote the genesis of felspathoids (*inter alia*), the desilicating and basifying constituents of a calcareous sandstone, for example, must be pitted against the effects of its silica-content. We are entitled also to anticipate the problems which might arise by the assimilation of carbonate-rocks associated with salt-deposits, gypsiferous shales, native sulphur, and carbonates and sulphates of strontium and barium.

In general, near-surface exposures of shales are dominantly potassic except where they have been adinolized by contact with basic intrusions. Even about the contact of shales with granite-magma, initial increment of alkalies to the shales may be, on balance, an enrichment in soda preferentially.

Average sandstone is also dominantly potassic. Little or no information is available concerning the susceptibility of sandstones to albitization. In limestones, the alkali-content is usually negligible, but albitic limestones have been described by Dr. E. Spencer (1925).

Analytical data for the solid products of presumed syntectic magma suggest that, where shales and schists in particular were assimilated, these rocks were appreciably more albitic than the average for corresponding near-surface facies. There is evidence also that, in particular cases, the granitization of xenolithic shales and basic igneous rocks is characterized, at an intermediate stage, by alkali-enrichment definitely in favour of soda (Brammall and Harwood, 1932, 178 and 181 ; Nockolds, 1931, analysis ii, 504), and that towards the close of the reconstitution processes the alkalies (total and ratio) tend to be levelled out to approximate conformity with values prevailing in the environing magma—*pari passu* with other reciprocal exchanges.

Adinolization of shales in contact with basic intrusions is a familiar phenomenon and, as already stated, soda tends to be fugitive from even granitic magma. On the hypothesis of a basaltic substratum and large-scale assimilation of deep-seated sedimentaries, etc., it is at least possible that these rocks are somewhat more permeated by albite than corresponding near-surface facies. Available data show that, though soda tends to be eliminated during the formation of mylonites and schists (Wiman, 1932; cited by Professor A. Holmes), on balance, soda-content relative to potash rises with passage from shales, through phyllite, etc., to mica-schists (Daly, 1914, 400). It is possible also that the alkali-ratio characteristic of near-surface shales may suffer inversion when the shales are depressed to depth in a sinking geosynclinal. The progressive reconstitution of xenoliths suggests that soda plays a "digestive" rôle in co-operation with the fluxes.

Geochemical evidence.

The general genetic problem, like igneous-rock classification, would benefit by being liberated from the tyranny of the SiO_2-percentage. The presence of modal quartz in certain basic rock-types may (as Daly suggests) imply a quartzite-gabbro (or similar) syntexis; on the other hand, even plateau-basalt has a potential source in amphibolite, etc. (Compare its position relative to other basalts in Fig. 1.) Criteria needed engage all constituents—minor as well as major. By eliminating normative quartz from analytical data and plotting the results in the triangular diagrams figured, attention is focussed on variation in the ratios of (*a*) salic to femic constituents and (*b*) Ab to Or + Cor. The fields occupied by igneous-rock series under investigation may then be compared with fields proper to both theoretical differentiation-suites and crustal rocks—both sedimentary and metamorphic.

Diagrams.

Data plotted are computed from Daly's standard "averages" (1914, 19–28 and 400, excepting "shale" average; 1925, for "plateau-basalt"—cited by Tyrrell), Clarke's "shale" average (1916, 28), and from published works cited in reference to particular igneous-rock complexes.

Bulk composition is plotted in terms of percentage norm-species exclusive of quartz; hence pure quartzite is excluded from the diagrams, which are not strictly applicable to undersaturated rocks. Norm corundum is insignificant except in the middle and upper fields.

The diagrams focus attention on ratios, and amplify the meaning of variation expressed by smoothed curves plotted against SiO_2-percentages.

In Fig. 1, for example, the "adinole" point expresses the ratios not only for adinole proper, but also for any "adinolic" matrix of quartzite, sandstone, etc. grading into schists.

Similarly, the line *cd* in Fig. 2 expresses the significant differences in composition between shale, spilosite (with desmosite), and mica-schist. The line joining "Shale" and "Limestone" spans the variation-range commonly displayed by a sedimentary series; any point on that line has its hornfelsed and schistose correlatives.

Though three fields—sedimentary, metamorphic, and igneous—are shown in Figs. 1 and 2, each field overlaps, and may be almost coextensive with, the other two.

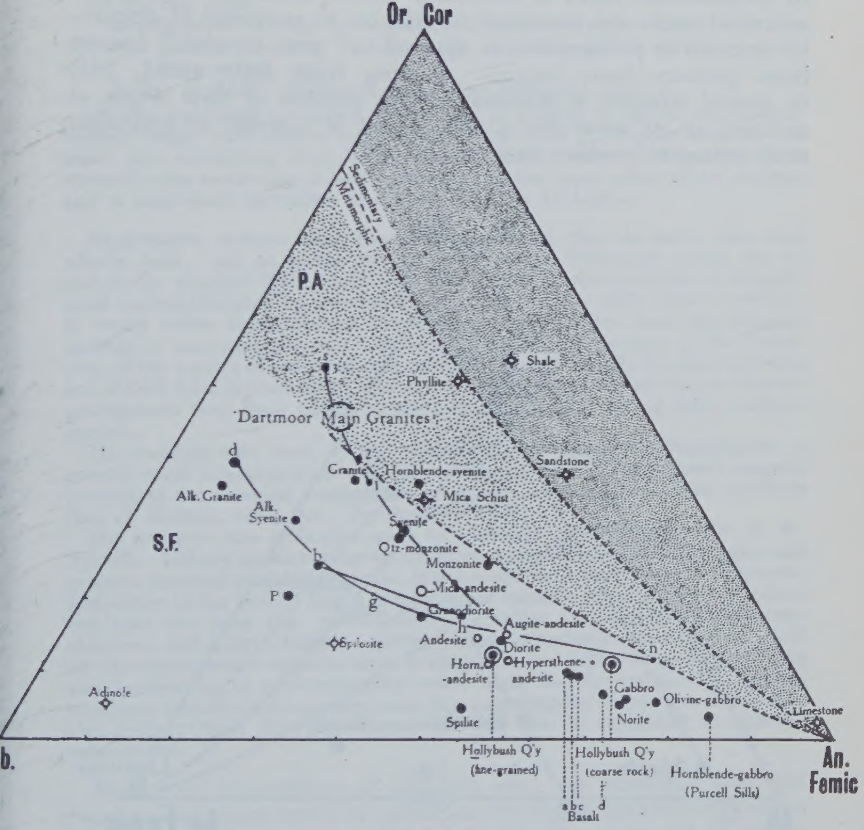

FIG. 1.—The average normative composition (excluding quartz) of the commoner rock-types. *For data plotted, see p. 100 ; also Sundius (1930, 9) for " spilite ", and Daly 1914, 320) for the Purcell sills.* Where syntexis is in question, the plotting of a variation-series may illumine data based on xenoliths, etc., and suggest both the magma-type and the crustal rocks concerned. E.g. :—The curve S, for the Shap Series, runs smoothly from the potash-aplogranite field towards " augite-andesite "—via granites 3, 2, 1, and hybrid " early basic " to an andesite-inclusion (Grantham, 1928). Syntexis of an " alk. granite " with spilites and diabases, and a modification of this syntectic by shales, would interpret the Dartmoor main granites, their marginal and hybrid facies, and their basic inclusions (Brammall and Harwood, 1932). The curve dgn links three terms in the Dhoon complex (Nockolds, 1931). The line hb links the two Ballachulish terms (Walker, 1924); the granodiorite, h, crowded with xenoliths, and the trondhjemitic " white granite ", b, a simple differentiate from h and free from xenoliths.

This preliminary plotting may afford some lead regarding the kind of criteria needed to establish, or disprove, consanguinity in particular cases. In the following sections (from which all reference to felspathoidal rocks is excluded) certain saturated and supersaturated rocks are examined in relation to problems of origin—by syntexis or palingenesis, as opposed to " pure-blooded " descent from primary basic magma. Quoting from Daly (1914, 343) *in special reference to granites: " The problem of their origin is so broad in its scope that it may almost be regarded as equivalent to the petrogenic problem as a whole."*

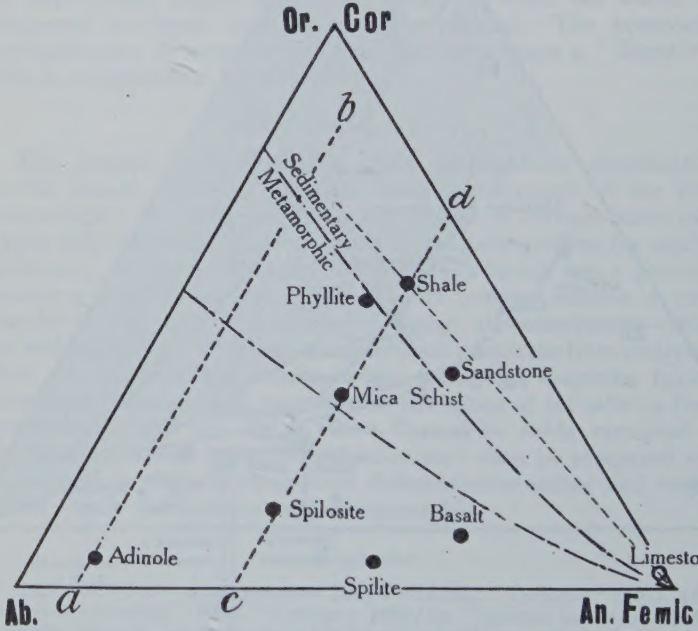

FIG. 2.—Illustrating the discussion, p. 99, of albitized sedimentary and metamorphic rocks.

Initial granite-magma.

The literature on granite-origin is too extensive to be listed here. Opinions differ mainly concerning the relative effectiveness, or scale, of individual processes not disputed. But seemingly opposed views are in some measure reconcilable, as is indicated by a recent discussion of the problem by Professor P. Eskola (1932) :—

Eskola sets out to explain why granite, which predominates in the most ancient of pre-Cambrian areas, is reduced in status when associated with successively younger formations. He also seeks to reconcile two seemingly opposed facts; the downward increase in the amount of granite in the upper parts of the earth's crust, and the downward increase of basicity in the globe as a whole. He extends his intimate knowledge of pre-Cambrian massifs to the interpretation of granites in general, and draws the following conclusions :—

(1) The sial crust
  (*a*) originated mainly by crystallization-differentiation allied with the partial (selective) re-fusion and squeezing out of substance from older rocks; and
  (*b*) has gradually thickened during the geological ages.

(2) The downward increase in the amount of granite is due to its magmatectonic origin—the magma originating in the roots of orogens and, for the most part, solidifying there—whereas the reduced amount of granite near surface is due to the rise of basic material into the upper zones of the orogens and to large-scale extrusions of basic lava in the kratogens.

He assumes, without being absolutely convinced, that the earth was once wholly fluid; but he points out that his general inferences would not be essentially modified if the earth were regarded as an accumulation of initially solid materials heated up from within (but cf. Holmes, 1927, 276–7)—whence it would follow that, through the ages, palingenesis has been the primary method of producing magmas. His considered opinion is that, in the formation of the earth's lithosphere, differentiation (preferentially by the squeezing out of fluid from crystal-mesh) was most effective in the earliest stages, whereas palingenesis may have played a more important rôle during later orogenic periods.

He contends also that, by the theory of crystallization-differentiation, a granite could originate from any silicate-magma (even plateau-basalt magma) containing the chemical components of granite, however small their amounts (but cf. Holmes, 1931, 243; Fenner, 1931, 540).

His reasoned case embodies notes by Professor A. Holmes and Dr. G. W. Tyrrell. Holmes agrees that an assimilation-series between basaltic magma and granitic material would differ little, in composition at least, from a differentiation-series in the line of liquid descent from basaltic magma. Tyrrell points out that the later (i.e. post-Cambrian) granites are largely granodiorites, tonalites, and quartz-diorites—corresponding to andesites and dacites which are the characteristic eruptive lavas in orogenic zones (1917, 311)—some mixing and basification of sub-continental melts being thereby indicated; he also considers that the only granite occurring in kratogenic zones is a differentiation-product from the great lopoliths, and can be regarded as entirely subordinate.

Numerous occurrences of granites, etc., are markedly aberrant from the standard trend of variation consistent with direct descent from primary basic magma (Fig. 1). The aberration displayed by the hornblende-syenites and quartz-monzonites, for example, hints at (but does not establish) syntexis, and the overlap of composition-fields furnishes further hints concerning alternative (retrograde or progressive) modes of origin and the possible composition of rock-substance concerned in a syntexis. In several cases recently described, the material actually assimilated corresponds rather closely to one or other of possible alternatives predicable from plotted data.

On the basis of "averages" normal basic and intermediate rock-types contain soda in molecular excess over potash, and the typical variation-suite (gabbro-granite) traces a curve represented approximately by the main stem in Fig. 3. This stem is merely medial—between those shown as traversing the upper fields and others (not plotted) traversing the dominantly sodic fields, in which " Spilite " occurs as a possible focal or pivotal point co-ordinate with " Basalt ".

This stem is not the exclusive locus of terms originating by " pure-blooded " descent from basic magma. For example, the syntectic hornblende-biotite-granodiorite of Ballachulish (h, Fig. 3) described by Dr. F. Walker (1924) lies close to this main stem ; a trondhjemitic granite-differentiate from this hybrid (g, Fig. 3), and its Dartmoor analogue (P, Fig. 1) are close to it ; granodioritic inclusions (granitized basic igneous rocks) in the Dartmoor granite also fall on, or near, this stem ; so also do the granodioritic, dioritic, and tonalitic hybrids (basified granites) of the Ronez complex (Wells and Wooldridge, 1931) and the Tregastel-Ploumanac'h complex (Thomas and Campbell Smith, 1932). On the other hand, the granite basified by greenstones in the Dhoon complex (Nockolds, 1931) is of alkali-granite type—closely comparable with the quartz-porphyries associated with it.

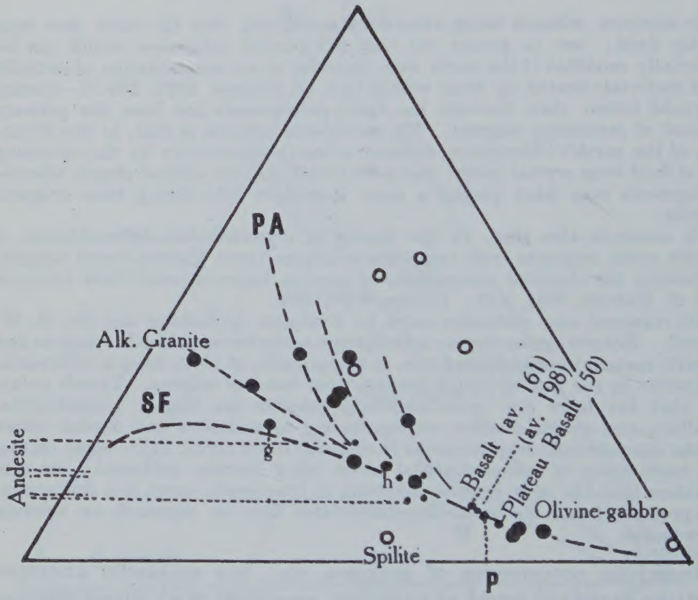

Fig. 3.—A generalized variation-stem for the igneous rocks plotted in Fig. 1. PA : Potash-aplogranites, etc. SF : Soda-felsites, etc. P : " Primary basaltic magma " (Daly, 1914, 315).

Even granites thus basified are not necessarily " pure-blooded ". Aplogranite differentiate from basaltic magma should veer towards the " albite " pole as biotite is eliminated ; but, as already pointed out, the sodic character of such an end-term does not, in itself, establish direct descent from basaltic magma. The successive intrusion-stages in the Shap complex (1, 2, and 3, trend s, Fig. 1), to which a "monzonitic" type is anterior, show a progressive increase in potash relative to soda with decreasing effects of contamination by country-rocks, mainly andesites. The plotting of the analytical data (Fig. 1) suggests that the magma basified may have been initially a potassic aplo-type represented by some point in the field shared by granites, potash-aplites, granophyres (not shown), slates, and phyllites. The origin of this initial magma is itself a problem, pursuit of which would necessitate a comparative geochemical study of related quartz-porphyries and aplites, the Palaeozoic floor- and flank-rocks, with desirable collateral work on other Lake District granites, particularly those emplaced in a more exclusively sedimentary setting. In the same way, the genetic problem raised by the "initial West of England" granite-magma is linked with the spilitic character of preceding igneous activity within this province, and its effects on shales, etc., at depth.

In the Dartmoor complex particularly, manganese is one of several "key" constituents. It is specially concentrated in the accessory species garnet—a manganiferous almandine in which the MnO ranges between 3 per cent and 22 per cent. Two or more varieties of garnet may occur in a single quarry or in a single hand-specimen of the granite. For the manganese and iron in these garnets the writer (1932, 191) entertained two likely sources: (1) the spilites, etc., and their ochreous residuals, and (2) manganese-rich bands in the shales. But no garnet of any kind has been found in the basic igneous xenoliths, and grossularite, not almandine, is the variety found in the contact-altered spilites of Peek Hill. On the other hand, a hornfelsed shale-xenolith containing only 0·19 per cent MnO has yielded a manganiferous almandine containing about 5 per cent MnO.

Each of these complexes presents a problem within a problem—the origin of the "initial granite-magma" which was basified. Turning now to the other extreme: where acidification of basic rocks has occurred, the basic initial term is sometimes recognizable and open to complete study: it approximates more closely to an "ultimate parental magma" than do the granites which have been basified. But even basalt-magma has more than one potential source: e.g. in the fusion of deep-seated amphibolites, etc., the re-fusion of basic substrata, selectively or in mass.

The examples of both derivative granite-magma and basified granites cited offer several main (and subsidiary) types of "initial granite magma" as convenient starting points for a census of possibilities attendant on basification: lines directed from each of these "initial" points in the diagram into various fields (igneous, metamorphic, and sedimentary) may assist in the interpretation of variation actually observed in the field, and suggest appropriate petrological and geochemical facts to be looked for in igneous rocks, xenoliths, and country-rocks alike, to establish or disprove the effectiveness of contamination, etc. There is, of course, no logical reason to assume that syntexis engages only the two extreme (granitic and basaltic) types of magma, or that any fixed composition is implied by " limestone ", " shale ", etc., contributory to syntectic mixtures. Nor are lava-flows to be summarily excluded from the scope of inquiry : Fenner mentions phenomena (1931, 542) which, he believes, cannot be explained otherwise than by solution, on a large scale, of basic andesites and basalts by rhyolitic extrusives, without loss of fluidity. Sufficient proof of contamination and hybridization of granitic and basic magma has been established to lift the general hypothesis above the plane of controversy. Questions of scale, i.e. the quantitative importance of the processes in particular cases, remain to be determined, and these questions force upon us a realization of the volume of work still to be done in order to appreciate, fully, what magmatic reaction on xenoliths, etc., can do to obliterate visible evidence of contamination (cf. Fenner, 1931, 542, par. 4). As a " blood test " applicable to rocks, the geochemical study of consanguinity may amply justify itself.

The work of Dr. F. Walker on the Ballachulish complex (1924) admirably illustrates both methods and lines of inquiry.

The main type (from which the " white granite " has differentiated) is a hornblende-biotite-granodiorite containing a " vast number " of small xenoliths—originally schists, with some proportion of pyritous slate. Zinc and copper were detected in the complex, the character and setting of which suggest olivine-gabbro as a possible " initial " term :—

Taking the composition of " av. olivine-gabbro " as a standard, a limiting composition for the schists, etc. digested is determinable. On the hypothesis of forefront albitization of the schists incorporated, this limiting composition should bear some resemblance to an albitic facies of argillaceous schist averaging the types intruded. The computed composition is :—

SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	H_2O, etc.
64·5	18·8	—	2·5	1·8	3·4	4·0	3·4	0·2	0·2	0·3	0·9

On this basis the granodiorite would equate a syntectic composed of about 75 per cent olivine-gabbro and 25 per cent schists.

Pursuit of the zinc and copper detected, and the search for other minor constituents appropriate to the case, would then follow.

This computation does not assert an olivine-gabbro parentage ; it merely serves to illustrate the kind of tentative hypothesis amenable to geochemical study.

Miss A. E. Cook (jointly with the writer) is investigating a similar problem presented by the peculiar facies of hornblende-gabbro (Fig. 1) with associated dioritic and acidic types, emplaced in Malvernian Schists at Hollybush, near Eastnor, Herefordshire. Analytical data for the gabbroid type and a microdioritic facies are plotted in Fig. 1. The genetic problem presented by this intrusive body was pointed out to the writer by Professor A. Holmes in 1920.

This brief contribution to the discussion puts forward no new hypotheses: it merely suggests the extent to which the geochemist and the petrologist could work in still closer co-operation in a common purpose—to lift the assimilation-hypothesis from the arena of controversy and furnish data whereby its importance may be viewed to scale in particular cases.

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Two Bibliographies of the Foraminifera.

By W. A. Macfadyen, Sedgwick Museum, Cambridge.

It has been said that there is no bad beer, but some is better than other, and this dictum holds, I think, for bibliographies of the foraminifera. Dr. C. D. Sherborn's well-known Bibliography (down to 1888) and his Index to genera and species (down to the end of 1889) set a standard that has not been maintained in later bibliographies. Finding a slip or omission in these two works one feels with Little Jack Horner " What a good boy am I ! ".

With the bibliographies of Woodward (somewhat pungently criticized by Sherborn in *Nature* (1888, xxxvii, 583)), Tutkowski and Winter it is not proposed to deal here. There are, however, two later bibliographies, that of Beutler,[1] which aims at listing all published papers dealing with the marine foraminifera down to the end of 1910, and that of Liebus,[2] which proposes to carry this on, listing all papers published in the years 1911–1930 inclusive. Of these two no review is known to me, other than a short notice of Beutler's by R. J. Schubert.[3]

Beutler's is a most useful publication and lists no fewer than some 3,870 papers, including many that are little known, published separately or in periodicals difficult of access. Those which deal with living faunas are starred. A valuable final section collects the others into groups concerned with faunas of the same geological age, and further subdivides them geographically. On the other hand, the titles of many papers are incorrectly given, a number being contracted and in some cases even paraphrased into a rough shortened title in German. No page or plate references are given, so that errors, which are not few, in the year of publication or volume number of a periodical may entail much loss of time in tracing a paper. The letters W or L are appended to many papers to indicate whether they contain description of species or alternatively only lists or mentions ; but these letters are not infrequently misplaced. An example of what one must be prepared for is the entry : " Hutton, F. W., Oxford Chalk Foraminifera, *New Zealand Journ. Sci.*, 2, 1906, W." Reference to the final section shows that this paper should deal with the Jurassic of Australasia. A search proved that the year of publication was 1885 ; that since the foraminifera are only mentioned the paper should have been marked L and not W ; and that they are recorded from the Chalk (Upper Cretaceous) of Oxford, New Zealand.

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[1] K. Beutler, *Paläontologisch-stratigraphische und zoologisch-systematische Literatur über marine Foraminiferen fossil und rezent bis Ende* 1910, München, 1911, 8vo, 1–144.

[2] *Fossilium Catalogus. I. Animalia.* Editus a W. Quenstedt. Pars 49. A. Liebus, *Bibliographia foraminiferum recentium et fossilium II* (1911–1930), Berlin (W. Junk), 1931, 8vo, 1–36.

[3] *Jahrb. k.k. geol. Reichs.*, Wien, 1911, p. 386.

Another paper, included under the name of W. Deecke, on New Rhizopoda, 1884, is also labelled W. It proved to be by a different author, T. Deecke, who described but did not figure " an unnamed protozoan which produced perforations in the plates at the bottom of a tinned copper water tank ". Omissions have not been checked in detail, but some well-known papers are missing, even of the older literature recorded by Sherborn, and even an author of the importance of Henry Sidebottom. Certain papers are included, like that of T. Deecke above, which are not concerned with the foraminifera, or which may contain no more than a bare reference to a single genus, as that of W. F. Hume, 1904.

Liebus's bibliography is well done so far as it goes ; and relatively few errors have been noted in authors' names, etc., though Henbest appears as Heubest, R. E. Stewart disconcertingly as Roscoe, E., and M. P. White as Mayn, White P. In the more important matter of the references, date of publication and volume, page, and often plate references are given, and correctly where they have been checked, in nearly all cases. The great defect, and a most serious one, is the lack of anything approaching completeness. In the whole work 722 papers are listed, according to my counting, with a few included twice over, once under wrong joint authors' names. I have checked through the whole bibliography with my own card index (to the benefit of this, which is based on the yearly bibliographies of the *Zoological Record*, with other information added), strictly under the same terms of reference, and I find no fewer than 450 papers omitted by Liebus that should certainly have been included. Thus at least 38 per cent of the papers dealing with the foraminifera and published between 1911 and 1930 has been missed. These include not only papers with mere passing mention of foraminifera but many of importance and easily accessible. Some authors fare worse than others. Thus some twenty-four papers are missed from the list of 161 of those of Cushman and his collaborators, but fourteen are missed to eight listed of Abrard's papers, and thirty-two are missing from H. Douvillé's name. Of Heron-Allen and Earland's papers (or those of the former author alone, which are not differentiated) twenty-one titles are missing.

A copy of this bibliography cost me seven shillings and threepence, no small price for thirty-six pages of text.

Professor Liebus ends his foreword by promising a new list of the older literature of the foraminifera, since the earlier bibliographies are now almost unobtainable, and since a bibliography is a necessary preliminary to preparing an index of genera and species. It is sincerely hoped that Professor Liebus will carry out both these most useful projects, but if the second is to avoid being a snare and delusion it must be based more firmly than on his own and Beutler's bibliographies.

Notes on the Geology of Sula Sgeir and the Flannan Islands.

By MALCOLM STEWART, B.A., F.G.S.

THE islands which form the subject of the present paper are remote Hebrides situated in the North Atlantic Ocean, Sula Sgeir being off the north coast and the Flannan Islands being off the west coast of the Lewis. Owing to their almost complete inaccessibility practically nothing was formerly known concerning their geology. While some of the islands had been previously visited by two geologists in the beginning and latter half of last century, others had never been landed on at all. The author, however, was happily able to visit all the islands, thanks to passages granted by the Commissioners of Northern Lighthouses, Captain Warman of Grimsby, and Mr. Malcolm MacLeod of Bernera, and thus to gather a few geological notes on these islands during the short time at his disposal in the summer of 1932.

SULA SGEIR.

The island of Sula Sgeir (Sulisker) lies some 40 miles N.N.E. of the Butt of Lewis in latitude 59° 6′ North and longitude 6° 9′ West, the nearest piece of land to Sula Sgeir being the small island of North Rona some 11½ miles to the east. The island is in reality little more than a large rock, its maximum length being only half a mile N.N.E.–S.S.W., while it has a maximum breadth of 200 yards. For simplicity the island may be regarded as consisting of two equal-sized portions separated the one from the other by a low and narrow ridge of rock over which the sea breaks in stormy weather. The southern half attains a maximum height of 229 feet, while a nearly similar reading is recorded from the north end. Like the majority of these exposed islands, Sula Sgeir is completely bounded by cliffs of considerable height. Marine erosion has here given rise to a large number of caves and geos : one of these geos has cut through the breadth of the island in the form of a tunnel. Sula Sgeir is devoid of any vegetation, save in parts of the southern portion there is to be found a scanty covering of thrift and chickweed. The island, which is one of the largest of Scottish gannetries, contains the remains of some five " dry stone " bothies, built by the men of the Lewis in the days when they used to make their annual visit to snare the young birds.

Geology.

Previous to the writer's visit very little was known concerning the geological structure of the island. MacCulloch, who voyaged through the entire Hebrides and has added much to the geological knowledge of the Western Isles, states that he was unable to land on Sula Sgeir (1), (2).[1] Heddle, however, set foot on the island, for he especially mentions "the highly felspathic and pale tinted variety of the rock" (3), and records the rose tint of the felspar (4). As far as the writer is aware there are no other geological accounts written by men who have visited the island.

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[1] Figures in parentheses denote list of references at end of paper.

The island of Sula Sgeir consists of hornblende-gneiss alternating with veins of pegmatite. The gneiss is almost jet black in the unweathered hand specimen. This is due to the high percentage of ferro-magnesians present, individual crystals of the hornblende often producing a remarkably high lustre. Small white translucent crystals of felspar are also in evidence. The rock is for the most part of moderately coarse texture. Thin sections show under the microscope that the ferro-magnesians, which occupy a large portion of the rock, consist almost entirely of hornblende. This hornblende, which is deep green, is highly pleochroic in all sections. This mineral occupies from 30 to 40 per cent of the rock. Other ferro-magnesians are also present, biotite and augite often being in evidence though always subsidiary to the hornblende. All sections show a remarkable absence of oxides of iron. The felspar is for the most part orthoclase, though microcline is by no means an unusual constituent. Quartz is usually absent, though a small percentage is to be found in a few sections. This gneiss in many ways resembles that of North Rona (7), only the garnetiferous variety so well displayed on that island is entirely absent from Sula Sgeir. It should be noted also that biotite was not found in the gneiss of Rona.

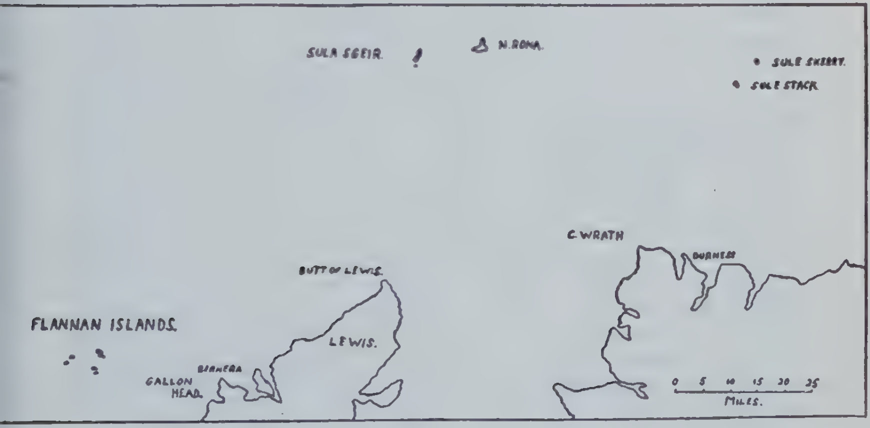

FIG. 1.

The pegmatite veins of Sula Sgeir consist of quartz and microcline. While in colour the quartz is for the most part white or occasionally smoky, the felspar is salmon pink. The colour of the microcline was noted by Heddle (3), (4). It is sometimes possible to discern a graphic structure. The pegmatite veins, though very numerous, are always small in size, few measuring more than two to three feet in breadth. Nowhere do they begin to compare with the massive veins which are so characteristic of North Rona. Like that island, however, the veins trend in a general E.–W. direction. Another feature of these veins is the gradual absorption of ferro-magnesians in the outside edges of the vein, it often being difficult to determine where the pegmatite, as distinct from the gneiss, commences.

There is nothing noticeable on the island to indicate any direct relationship between the geological structure of the rock and the topography of the island. The apparent dip of the gneiss is in a general northerly direction in the southern half of Sula Sgeir, but becomes more westerly towards the north.

Glaciation.

The question of the glaciation of these remote islands is always a difficult one. In the case of Sula Sgeir, however, a direct comparison with North Rona is the most satisfactory course to adopt. James Geikie always assumed that the Quaternary ice swamped these two islands (5), but since he did not visit either of the islands himself, further evidence is needed to substantiate his assumption. On Sula Sgeir there is to be found no raised beach as on North Rona (7), and in common with that island no glacial striae were observed. This is hardly surprising since the exposed position of Sula Sgeir and the constant marine erosion to which it is subjected hardly tend to the preservation of such phenomena. However, a few small pieces of rock alien to the island were found on Sula Sgeir. One of these much resembled a fine-grained Torridon Sandstone. This seems to suggest that the Quaternary ice was the means of transportation. If one assumes, and indeed the evidence supports the assumption, that the Quaternary ice reached North Rona, it is also safe to assume that it also reached Sula Sgeir, only 11½ miles distant.

THE FLANNAN ISLANDS.

The Flannan Islands or Seven Hunters are a group of small islands in latitude 58° 17′ North and longitude 7° 35′ West. They are therefore some 20 miles west of Gallon Head, the nearest point of land. The rocks and islands constituting the Flannans are numerous, though seven only are of any size. The islands arrange themselves into three groups; a northern group consisting of Eilean Mor and Eilean Tighe, a southern group consisting of Soray, Sgeir Toman, and Sgeir Righinn, and last a western group consisting of Roareim and Eilean Ghobha. The distances of the northern group from the western and southern groups are respectively 1½ and ½ miles. The islands, which are all cliff-bound, are of an irregular oval shape. They are all exceedingly small in size, the largest, Eilean Mor, being only some 30 acres in area. All the islands have a covering of grass and chickweed which affords pasturage for sheep. The Flannans are all uninhabited except for the lighthouse on Eilean Mor erected by the Commissioners of Northern Lighthouses in 1899. This lighthouse is built on the summit of the island at a height of 288 feet.

Geology.

Except for a short account of the geology by MacCulloch (1) and a visit to Eilean Tighe by Heddle (3) the details of these islands are unknown. MacCulloch's account though occupying some three and a half pages is really of little importance. He does not even mention on which island he landed. One knows that Heddle landed only on Eilean Tighe, but he makes no mention of the geology of the island at all. So as a matter of fact there is no geological account of any import on these islands; the writer also believes that no scientist has ever previously visited any of the islands except Eilean Mor and Eilean Tighe.

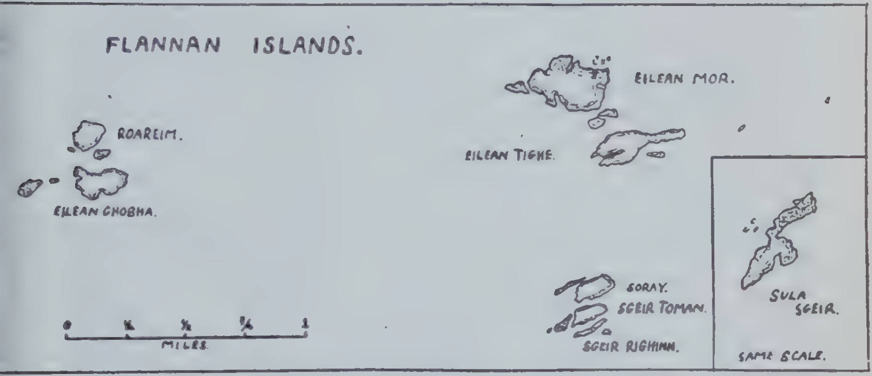

Fig. 2.

The Flannan Islands consist of hornblende-gneiss alternating with veins of pegmatite. The gneiss in many ways closely resembles that of Sula Sgeir, only biotite is a much more common accessory, while augite occurs in some sections. The ferro-magnesians also occupy a large percentage of this rock. On the Flannans too magnetite and other oxides of iron, almost absent from the gneiss of Sula Sgeir, are found in most of the rock sections. The felspar is mostly orthoclase though plagioclase with pronounced lamellar twinning is often present. In this plagioclase plates perpendicular to the twin plane have an extinction angle of − 8°. Both refractive indices are greater than 1·54 This felspar has all the characteristics of andesine. Microcline is not so common in this gneiss, while quartz is sparingly present in a few sections. The character and composition of this gneiss do not vary greatly from one island to another. The pegmatites, however, vary greatly when traced the length of the islands, so that the pegmatite of each island must be discussed separately. On Eilean Mor the pegmatites consist of white quartz and white felspar (microcline) with occasional crystals of biotite. The quartz crystals are sometimes large and coarse, but a well-defined medium-sized graphic structure is most common throughout the island. The largest veins, though always numerous and of no great size, are best displayed in the north and south cliffs. On Eilean Tighe the pegmatite is on the whole coarser. The quartz is usually darker in colour while the microcline is pink. Biotite is still occasionally present. With the exception of the occasional presence of this last mineral, the pegmatite here much resembles that of North Rona. On Soray the pegmatite is lighter in colour and the graphic structure not so obvious. It is similar to the pegmatite of Sula Sgeir. However, by far the best variety of pegmatite is to be seen on Roareim. The west end of the island consists of one enormous vein. This is the only vein of any size throughout these islands. It is even comparable in magnitude to those of North Rona. The felspar is pink and often in evidence as large crystals. The quartz is usually blackish though it sometimes exhibits a slight amethystine tint. There are few pegmatite veins on Eilean Ghobha and they are all insignificant. However, on the north side of the island low down by the sea is to be found a highly-coloured pink vein. The rock is much weathered and little can be made of microscopic examination of a thin section. It appears, however, to consist chiefly of small laths of twinned plagioclase felspar. Unlike those of Sula Sgeir, the pegmatite veins of the Flannans are distinctly bounded by the gneiss, there being no difficulty here to distinguish where a vein begins and the gneiss ends. The pegmatite veins of the Flannans, which all trend in a general E.–W. direction, often play a large part in the distortion of the gneiss. The effects of the intrusions of these veins are clearly seen in the steep cliff sections of Eilean Mor. MacCulloch even went so far as to suggest that several of these veins were in reality one vein thrown into a series of overfolds, the bottom of the structure being invisible while the top had been removed by subsequent erosion (1).

The apparent dip of the gneiss is northerly in the southern group, becoming north-westerly in the western group to westerly in the northern group. The dip of the rock, however, appears to have little effect on the general form of the land.

Glaciation.

As it is generally assumed that the Quaternary ice swamped the islands of the Lewis and the Harris, there is a strong possibility of it having reached the Flannans only 20 miles off the western coast. Direct evidence is, however, scanty. As is nearly always the case in small islands exposed to much marine erosion, there are no striae present at all. As on Sula Sgeir, however, small pieces of rock unknown on the Flannans are to be found on nearly all of the islands. One specimen is almost identical with that of a piece of rock found on Sula Sgeir, the rock being a type of fine-grained Torridon. On the top of Roareim, however, at a height of nearly 150 feet, there is a small area of a coarse breccia cemented with sand. This deposit, which is traceable for some 200 feet, much resembles a similar deposit on North Rona (7), and there is a strong possibility of it being a raised beach. Pieces of rock, mostly indigenous, both subangular and rounded, up to the size of one foot were found cemented together. There was no trace of organic remains in this deposit and acid tests gave negative results for calcium carbonate. Samples of the cemented sand were taken and subjected to screening, the following being the result of several similar readings.

	VCS	CS	MS		FS	s
Mechanical analysis .	30·66	20·67	10·91	11·43	17·68	8·07
Diameters > . .	1	0·5	0·294	0·21	0·099	< 0·099
Cumulative percentages .	30·66	51·33	62·24	73·67	90·75	98·82

For the sake of comparison the following table gives the readings of the deposit on Eilean Ghobha, Flannan Islands, together with those of similar deposits on North Rona (7), and at Balnakiel near Durness, Sutherland (6).

	FLANNANS.		N. RONA.		BALNAKIEL.	
	Per-centages.	*Cumulative per-centages.*	*Per-centages.*	*Cumulative per-centages.*	*Per-centages.*	*Cumulative per-centages.*
VCS .	30·66	30·66	24·15	24·15	—	—
CS .	20·67	51·33	20·53	44·68	0·6	0·6
MS .	22·23	73·67	37·28	81·96	50·0	50·6
FS .	17·68	90·75	7·53	89·49	41·4	100·0
s .	8·07	98·82	10·45	99·94	0·0	100·0

An interesting feature comes out of the above table. It appears that the farther west the deposit the greater is the percentage of the very coarse sand (VCS), while the further east the greater percentage of the medium-sized sand (MS). It should also be noted that the figures of the Flannans and North Rona are very similar for the coarse sand (CS) and for the silt (s).

SUMMARY.

Sula Sgeir consists of hornblende-gneiss with occasional biotite and augite. The whole is intersected by small pegmatite veins which merge along the borders into the gneiss. Though evidence is small, it seems probable that the island, together with North Rona, came under the influences of the Quaternary ice.

The Flannan Islands consist also of hornblende gneiss, biotite being a fairly common accessory. Numerous and varied pegmatite veins occur throughout the islands, and in certain cases have affected the foliation of the gneiss. Owing to the proximity of the islands to the Lewis and the Harris, and the presence of a deposit of cemented sand on Eilean Ghobha, it seems probable that the Quaternary ice also reached these islands.

ACKNOWLEDGMENTS.

The author wishes to express his gratitude and thanks to Mr. J. Glencorse Wakelin, secretary to the Commissioners of Northern Lighthouses, for many helpful suggestions and granting a passage on the *Pole Star* to Eilean Mor with Flannan relief. The author also wishes to thank Mr. Malcolm MacLeod of Bernera for affording him the passage to the other Flannan Islands. The visit to Sula Sgeir by steam-trawler was arranged thanks to Mr. Keir and Mr. Thompson, of the Fishery Office, Aberdeen, and Captain Warman, of Grimsby.

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(4) —— *Mineralogy of Scotland*, Edinburgh, 1901.
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(6) Reid, D. M. "On a Raised Beach on the North Coast of Scotland," Geol. Mag., LXVI, 1929, 177–180.
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Gutenberg's Fliesstheorie; a Theory of Continental Spreading.[1]

By Philip Lake, M.A., F.G.S.

GUTENBERG is not a geologist but, as a geophysicist, he is directly interested in several of the broader questions of geology. He has been impressed by the simple way in which Wegener's drift theory seems to solve many geological problems, but he finds it impossible to accept that theory in its entirety. He has, therefore, tried to formulate another theory which is more in accordance with geophysical data, and which still solves the same geological problems. "Continental Spreading," a name suggested by Dr. Harold Jeffreys, expresses very clearly its dominant feature.

Wegener assumed that the floor of the ocean is a nearly level surface of sima and that the continents are sheets of sial floating in the sima. Even the soundings of pre-war days were sufficient to throw doubt upon this notion. They indicated that the floor of the Atlantic stands at a considerably higher level than the floor of the Pacific, and they proved that in the North Atlantic, where soundings were most numerous, the floor is decidedly irregular. The bathymetric map of the North Atlantic, in Murray and Hjort's *Depths of the Ocean*, a map compiled in 1911, shows in mid-Atlantic, about 50°–52° N.lat., parallel ridges and troughs running from a little south of west to a little north of east. The difference in depth between trough and adjacent ridge sometimes exceeds 5,000 feet. If we remember the general trend of the Armorican folds in western Europe on the one side and of the folds in Nova Scotia and New Brunswick on the other, it is difficult to resist the impression that these ridges and troughs belong to the same system of folding and that the Hercynian range here lies beneath the sea. Others besides myself must have received the same impression but, until the critical area has been more closely surveyed, the truth of the impression must remain doubtful. To draw attention to the matter I reproduce the relevant parts of Murray and Hjort's map. The thick line shown in the figure is an arc of the great circle which passes through Halifax (Nova Scotia) and Cork, and is inserted merely to guide the eye through the distortion due to the projection employed. The Hercynian range itself, so far as we actually know it, is formed of several arcs of shorter radius than this.

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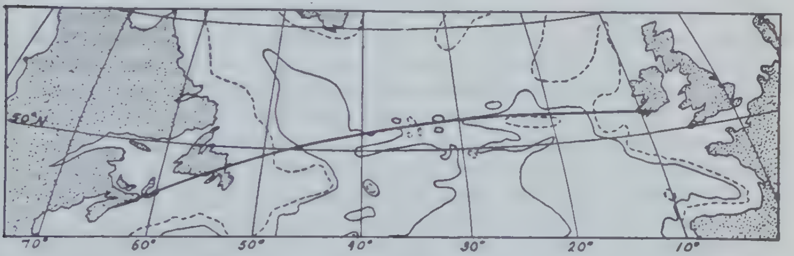
[1] *Gerlands Beiträge zur Geophysik*, xvi, 239, and xviii, 281; and *Handbuch der Geophysik*, Band iii, Lief 1, 532.



Part of the North Atlantic.

Contours after Murray and Hjort: 1,000 fathoms shown by a broken line; 2,000 fathoms shown by a full line. The thick line is an arc of the great circle passing through Halifax (Nova Scotia) and Cork.

The echo methods of sounding developed during and since the war are so rapid compared with the use of the lead that a much closer survey of the sea-floor is now possible than was practicable in former days; and the *Meteor* expeditions have already shown that in the Atlantic there is no such even plain as was before imagined. To account for the irregularities that have been found isostasy of the Airy type requires the presence of a lighter crust of varying thickness resting upon a denser layer below. Investigation of earthquake waves leads to the same conclusion. The observations indicate an abrupt discontinuity at the border of the Pacific but no such discontinuity at the border of the Atlantic. The material of the Pacific floor must be different from that of the continents; the Atlantic floor differs from the continents only in the thickness of its sial crust.

Such considerations have led Gutenberg to conclude that the bed of the Atlantic consists of sial and probably the beds of the Arctic and Indian oceans also; but the bed of the Pacific consists of sima. According to him all the continents, together with the Arctic, Atlantic, and Indian oceans, are included in one great sheet of sial, of varying thickness; only in the Pacific is the sial covering absent. The boundary between sial and sima follows approximately the "ring of fire that girdles the Pacific".

At first it may appear that this conception precludes any great alteration in the relative positions of continents or of sial-floored seas; but the sial was not always so extensive. The chief force that Gutenberg invokes to produce change is gravity itself, but the effect of gravity with which he is principally concerned is one that has not hitherto been seriously considered in this connection. A heap of solid pitch under the influence of gravity will spread outwards and the heap will flatten. There is the same tendency in a solid heap of sial, and apparently the strength of sial is not sufficient to prevent the effect, though the spreading is extremely slow. Below the surface of the sima the spreading is opposed by the resistance and pressure of the sima, and it is evident that, unless its own strength is too great, a mass of sial floating in sima will spread outwards over the sima, increasing in superficial extent and decreasing in thickness.

Another force which is involved in Gutenberg's reconstruction of past events is the "Polflucht" force, already familiar to geologists from the part that it plays in Wegener's theory. Its tendency is to drive any sheet of sial towards the equator and to place it in such a position that the total force acting upon the part in the northern hemisphere is exactly balanced by the total force acting upon the part in the southern hemisphere. In doing so it may turn the sheet about a vertical axis. When the stable position is reached the force still continues to press together the northern and the southern parts of the sheet.

Gutenberg supposes that the earth was originally covered by a continuous crust of sial, but when the moon departed most of this was carried away. The remainder was left as a single thick sheet placed asymmetrically about the south pole, the great part of it lying in what, for convenience, we may call the eastern hemisphere. It does not coincide with the eastern hemisphere of the usual map of the world in hemispheres, centred on the meridian of 70° E. The centre of our eastern hemisphere is more suitably placed at the point where the meridian of 20° E. crosses the equator—i.e., near the median north-to-south line of the present sial sheet.

After the moon had left two tendencies came into play within the sial remnant. Because it surrounded the south pole there was Polflucht force acting upon it in every direction from that pole towards the equator; but because the greater part was in the eastern hemisphere and that part stretched farther towards the latitude of maximum Polflucht force, the resultant effect was to drive the sheet as a whole towards some point of the equator in that hemisphere and, perhaps, to cause rotation about a vertical axis. At the same time under the action of gravity the sheet spread outwards in all directions.

This is the basis of the reconstructions attempted by Gutenberg. He accepts the past climatic zones of Wegener and Köppen and shows how they fit the movements of different parts of the sial sheet according to his hypothesis. By Carboniferous times the outward spreading and the northward travel had proceeded so far that in the eastern hemisphere the sheet stretched some fifty degrees beyond the equator, but it nowhere reached the Arctic circle. Gondwanaland lay in the south and included both temperate and cold climates; Great Britain was near the equator and had a climate favourable to the formation of coal; the parts of the sial that are now in the Arctic regions were still in temperate latitudes. Even in the Eocene period, though the northward spreading had carried them farther north, the Arctic regions of to-day had not reached the Arctic circle, and Great Britain lay in the warm temperate zone, perhaps about the present latitude of the Mediterranean.

Enough has been said to give a general idea of the course of events according to Gutenberg's hypothesis. The sial starts in the south. By spreading and, to a limited extent, by travelling under the influence of the Polflucht force, the part of the sial that now forms the Arctic regions has been carried across the equator into its present position, and other parts have been correspondingly transported through several climatic zones.

The spreading of the sheet induces weaknesses which subsequently develop into seas that rest upon it, such as the Arctic, Atlantic, and Indian oceans. We need not here go farther into this question, but there is another point which is of importance for the proper appreciation of the general theory.

The Polflucht force is not of itself great enough to raise a mountain range, but in a sial sheet that crosses the equator it aids the formation of a mountain range along the equator, more than in any other direction or position. Similarly, the spreading force cannot itself raise the edge of the sial sheet above the level of the rest, but it can assist in the formation of a range parallel to the edge. Thus, so far as mountain-building is concerned, the Polflucht and the spreading forces may be looked upon as guiding forces. If the earth were spherical, composed of concentric homogeneous layers, and did not rotate, contraction of the interior would have no more tendency to produce wrinkling in any one direction rather than in any other. A very small additional and localized force would then determine the position and direction of the wrinkles. On the actual earth, therefore, if subject to contraction, there will be folding along the equator, determined by the Polflucht force, and folding along the edge of the sial sheet, determined by the spreading. A geologist will judge for himself how far this corresponds with facts. It should be noted here that Gutenberg believes the sima to be stronger than the sial; seismological observations show that it is less compressible and that it offers greater resistance to elastic deformations.

A mountain range which has been formed at the equator does not remain in that position, but is carried northwards. A new range arises at the equator and also travels northwards; and so we may have a succession of ranges following one another, like the Caledonian, Hercynian, and Alpine systems of Europe. Rotation and spreading of the sheet may alter the direction of a range, and hence the difference between the Caledonian and Hercynian trends.

There is a physical difficulty in the general theory which Gutenberg does not seem to explain. The sial sheet starts in the southern hemisphere; the greater part of it now lies north of the equator. Neither gravity nor the Polflucht force can transfer more than half of it from one hemisphere to the other. Some other force must have come into action.

The great merit of the theory, from the geological point of view, is that it gives a reasonable explanation of the difference between the Atlantic and Pacific coasts, an explanation which is more complete than a brief synopsis can show. Also, as we have just seen, it accounts for the southward succession of the systems of folding in Europe, but not so convincingly.

It is unfortunate that Gutenberg relies so entirely on Wegener and Köppen for his geology and assumes that their past climatic zones represent past realities. Consequently, his reconstructions have the same defects as theirs. It would be a waste of space to repeat objections which have often been raised, but Gutenberg faces a difficulty which Köppen and Wegener evade. If the Polflucht force and the westerly drift will not bring the continents into the position they want, Köppen and Wegener move the poles. Gutenberg is more constrained. He has no independent movements of the poles, and he cannot alter the direction of his sial movements as he likes. Consequently, there is a much better test available than is afforded by hypothetical climatic zones.

Throughout the greater part of Gutenberg's sial sheet the movement must have been northerly. Towards the eastern and western edges the east or west component may be much the strongest, but in the eastern hemisphere a north component will not usually be absent even here. In the western hemisphere there may have been some southerly movement and, perhaps, rotation of the sheet may have introduced a limited southerly movement into part of the eastern hemisphere. But an area like Great Britain, which lies well in the midst of the sheet, must have moved continuously northward, though not necessarily due north. It must have passed in succession through all the climatic zones which lie between its starting point and its present position, and it never turned back.

We may suppose that during Torridonian times Great Britain lay near the Antarctic circle ; frost was the dominant weathering agent, and seasonal floods due to melting of the snow were the chief means of transport. From the Cambrian to the Silurian period it passed through the south temperate zone. The Old Red Sandstone was laid down while it was in the southern dry belt, Scotland being above the sea and south Devonshire beneath. During the Carboniferous Great Britain was on the equator and during the Trias it was evidently in the northern dry belt. From the Jurassic to the Eocene it travelled through the warmer part of the north temperate zone and reached our present latitude in the Pliocene. We need not conclude that it went to the Arctic regions in the Glacial period and came back again, for other causes may have temporarily lowered the temperature.

It is an impressive history, more consistent than the lawless wanderings imagined by Köppen and Wegener. It would be easy to find faults in it ; but any useful discussion of the evidence would require many pages of the GEOLOGICAL MAGAZINE, and the object of this paper is simply to introduce to the notice of English geologists the suggestions of a well-known geophysicist. He recognizes that these questions cannot be solved by geophysics alone, or by geology alone.

Notes on the Species *Illaenus bowmanni* Salter.

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THERE has been considerable uncertainty about the true characters of the species *Illaenus bowmanni* Salter,[1] and many foreign palaeontologists have consequently found it difficult to institute a close comparison of it with other species and have suspected its composite nature. As Holm [2] and Warburg [3] have remarked, the species is badly characterized, and some important critical features, such as the shape of the caudal fascia, are ill-defined or not clearly described in the definitions or well represented in the figures. The poorness of the specimens is largely accountable for these omissions. A recent detailed investigation which the author has been enabled to make of the specimens used by Salter, Portlock, and McCoy in drawing up a definition of the species, together with the examination of many other specimens ascribed to it from the original and other localities, throws some useful light on the subject and helps to clear up some of the obscure points, but it also shows that most of the earlier and current synonymies and references which have been published from time to time are untrustworthy and inaccurate.

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[1] Salter, *Mem. Geol. Surv.*, ii, pt. i, 1848, 339, pl. viii, figs. 1, 2, 3 ; *Mon. Brit. Trilob.*, pt. iv, 1867, 185, pl. xxviii, figs. 6–13, pl. xxx, fig. 6.

[2] Holm, *Rev. Ostbalt. Silur. Trilob.*, Abt. iii, 1886, p. 153.

[3] Warburg, *Trilob. Leptaena Limest.*, *Bull. Geol. Instit. Upsala*, xvii, 1925, 123, 132.

We will first of all discuss Salter's figured specimens. Salter chose as his type a cranidium, somewhat crushed and distorted, from Sholeshook, South Wales, No. 24553, now in the Jermyn Street Museum, and it is from this specimen that we must get our conception of the specific characters. With this type-cranidium No. 24553 there are four other specimens mounted on the same tablet, all from Sholeshook, one of them (No. 24556) being a cranidium rather better preserved and less crushed; the other three are pygidia in a more or less imperfect condition, but only one (No. 24554) was figured by him, and is now described.

His original description which is quoted below was based on the cranidium, No. 24553, which is the first specimen figured, but Dr. Stubblefield believes that Salter used also another specimen from the same locality (No. 24556) in constructing this figure. But the specimens of the thorax with attached pygidium (op. cit., fig. 2), No. 35576, and of the small complete individual (op. cit., fig. 3), No. 35575, were from Tyrone and had been figured previously by Portlock. The specific description of *I. bowmanni* was given [1] by Salter as follows: "Smooth, cephalic and caudal divisions nearly equal, each longer than the short thorax of nine segments; axal lobe of head with converging furrows, less than half-way up; eye very near the outer edge, about its own length from the neck margin, and subtended by a strong neck furrow; axal lobe of body not convex, a little broader than the narrow flat pleurae which are slightly bent back at the fulcrum at half, and convex from thence. Head rather larger than the caudal shield, and convex; the eyes small, semilunar, very distant; this latter character will easily distinguish it from the preceding species [*I. Rosenbergi* Eichw.], also from *I. crassicauda* and from *I. Davisii*."

There are two inaccuracies in this description, if we examine the first figured cranidium, No. 24553; firstly, the glabella has not convergent axial furrows, for they are almost parallel; and secondly, the surface of the carapace is not smooth but pitted and punctate. His figure, however, of this specimen, though only an outline, is fairly correct, though in the side-view (op. cit., fig. 1*a*) the convexity from back to front is less regular than it is represented, the posterior half being noticeably flattened and the anterior half arched down. Dr. Stubblefield believes that this profile (fig. 1*a*) is more like the other specimen, No. 24556. In his monograph [2] Salter again gives merely an outline of No. 24553, and in both cases he has somewhat restored it and corrected the distortion and cracks. The anterior edge of the specimen is somewhat crushed and bent down along a crack near the margin, and the left fixed cheek is partly broken. The free cheeks are completely missing. The surface of the carapace is mostly abraded or very poorly preserved, but in places the pitting which he failed to mention can be detected with a lens.

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[1] Salter, *Mem. Geol. Surv.*, ii, pt. i, 1848, 339, pl. viii, figs. 1 and 1*a*.
[2] Salter, *Mon. Brit. Trilob.*, pt. iv, 1867, pl. xxviii, fig. 12.

The detailed description of this specimen is as follows: Head shield semi-circular, gently convex from side to side but flattened posteriorly and rising rather suddenly into a hump in the middle, arched down anteriorly rather suddenly at about two-fifths its length at about 130 degrees to posterior portion (the anterior marginal portion is broken and bent down suddenly owing to crushing). Anterior margin with narrow thickened rim. Glabella short, very wide, twice as wide as long, occupying about half the width of the middle-shield and about one-third its length, with scarcely any independent convexity; axial furrows strong, nearly parallel, very slightly sigmoidal, at first slightly convergent, then curving a little outwards at anterior ends but not expanded. Fixed cheeks very slightly convex from side to side but rather strongly arched down behind near the posterior margin. Eyes small, very far back, about their own length from posterior edge of head-shield. Occipital segment forming very narrow depressed meso-occipital ring marked off from glabella by distinct furrow; pleuro-occipital furrow much wider and widening outwards to eye. Facial sutures (not well preserved) with anterior branches subparallel, cutting margin of head-shield in front at about two-thirds its length; posterior branches very short. Surface of head-shield ornamented with small scattered circular pits and minute punctae.

In the specimen No. 24556 of a cranidium also from Sholeshook, which it is believed that Salter used partly for his figures 1 and 1*a*, the glabella is less flattened and rather less wide because the specimen is less crushed, and it has a slight independent convexity. The fixed cheek which is well preserved on the left side is about two-thirds the basal width of the glabella and the posterior branch of the facial suture is seen to run back at first at right angles to the posterior edge of the head-shield, but turns sharply outwards near it to cut it at an acute angle. The deep pit at the posterior end of each axial furrow is well seen, and the anterior marginal rim of the head-shield is well preserved.

Specimens of head-shields in the Sedgwick Museum collected by Dr. Marr and Mr. Roberts at Sholeshook are mostly somewhat crushed and distorted, but they agree in size and characters with Salter's figured types of *I. bowmanni* above described, and they undoubtedly belong to the same species. In one of these specimens (No. 285, Sedgw. Mus.) the left free cheek is still attached to the middle-shield and is nearly perfect; it has a broadly rounded genal angle, the edge from the posterior point of section of the facial suture round to the lateral margin forming a continuous semi-circular curve ; the greatest width of the free cheek is at the level of the eye and is about equal to the width of the fixed cheek ; there is a broad, shallow, rounded groove round the base of the eye ; the marginal portions of the free cheek are arched down, and they descend to the edge rather more rapidly than the rest of the surface, which is very slightly but not independently convex, sharing the general convexity of the head-shield ; and there is a very narrow rim round the lateral edge.

Salter did not describe the characters of the pygidium in the Survey Memoir of 1848, but in his Monograph [1] in 1867 he gave them as follows : " Regularly and gently convex, half a broad oval ; length two-thirds the breadth ; upper angles strongly truncated ; axis more than one-third the breadth, only marked out by broad indentations in upper part, having no true axial furrows ; margin neither obtuse nor recurved but regularly and evenly declining to smooth edge. Caudal fascia concave, rather narrow, especially towards upper angles, broader below and not indented by axis internally."

There are two pygidia from Sholeshook in the Jermyn Street Museum mounted on the same tablet as the figured type of the head-shield No: 24553, and these were presumably used by Salter in this description though they were not figured. One of them (No. 24555) is nearly complete, only the right lateral angle being missing and a portion of the posterior edge chipped ; a part of the fascia is exposed on it. Its shape is transversely subparabolic, not semi-circular, the convexity from back to front is slight, but the posterior marginal portion for about a quarter its length is rather suddenly arched down ; the transverse convexity is very slight. The axis, which projects slightly on the edge and is marked by rather deep marginal notches on each side, has a width of about one-third of the pygidium and possesses a slight independent convexity, but it is somewhat depressed in the middle posteriorly (probably this is accidental) ; and a triangular shape is clearly indicated and its length is seen to be equal to about two-fifths that of the pygidium. The fulcrum is situated at about half the width of the axis and is slightly raised on the edge with a weak short groove behind it. The lateral angles are broadly rounded and truncated at about 140 degrees to the front edge. The fascia, which is only partly exposed round the margin, clearly shows the subparabolic shape of the pygidium and is fully one-third the length of the pygidium in width posteriorly, but its inner edges are partly hidden, though they seem to describe a double concave curve meeting in a low. broad cusp in the middle, but not so acutely as in *I. linnarssoni* Holm (emend. Warburg).[2] The outer marginal half of the fascia is flattened but not convex, and the inner half suddenly bends up with a strong concavity and becomes closely appressed to the inner surface of the carapace. The concentric lines of the fascia are rather close and regularly continuous on the outer flattened portion, but on the inner portion they are rather wider apart and less continuous, having some shorter and intercalated lines in the median portion. The surface of the carapace seems to be covered with rather coarse, low, rounded, closely set granules often fused together into short sinuous lines, but it is very doubtful if this is an original character and not due merely to the mode and state of preservation or to the weathering of the specimen. On the inner part of the left lateral lobe near the axis there are several equidistant oblique parallel incised lines visible, and I have seen similar ones in a specimen in the Sedgwick Museum from Sholeshook. We may especially compare this pygidium with that of *I. oviformis* Warb.[1]

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[1] Salter, op. cit., 1867, 185–7.

[2] Warburg, op. cit., 117–123, pl. ii, figs. 14–18.

The other pygidium (No. 24557) from Sholeshook mounted with the type specimen of the head-shield consists only of the impression of the greater part of the external surface of the carapace, and it shows the terrace-lines which are found in many species of the genus. This specimen has not been figured. The width and projection of the axis on the front margin, its slight independent convexity the position of the fulcrum, shape of the lateral angles, and arching down of the margin of the pygidium behind seem to be precisely similar to the other one above described, but the pygidium is relatively longer and more semi-oval than parabolic, so that its reference to the same species may be rather doubtful.

The terrace-lines upon it form three discontinuous transverse series anteriorly, for they are only visible on the anterior and inner portions of the lateral lobes and on the axis, the marginal regions being smooth ; the lines on the lateral lobes are short, sinuous, broken, and bend back posteriorly at their inner ends ; those on the axis are fewer, wider apart, and arch forward, but are likewise sinuous and broken. Behind the axis the terrace lines of the lateral lobes more or less unite, and thus indicate that the axis had nearly half the length of the pygidium, but there are no axial furrows and not such a distinct indication of the triangular shape of the axis as in the other specimen (No. 24555). The rest of the surface of the carapace is covered with small, circular pits which are most distinct on the smooth marginal portion of the pygidium.

It is doubtful if both of these pygidia belong to the same species, the shape and proportions being rather different, even if we do not regard the surface ornamentation of the smaller one, No. 24555, as being original, and which of them should be associated with the head-shield from Sholeshook figured by Salter must remain at present uncertain. The smaller pygidium from Sholeshook (No.

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[1] Warburg, op. cit., 123, pl. ii, 19–24.

24554) figured by Salter in his Monograph [1] and described below is seen to belong to another species.

We turn now to the other figured specimens referred to *I. bowmanni.* Salter's figure of a thorax with pygidium attached (op. cit., 1848, pl. 8, fig. 2) is from one of Portlock's [2] original figured specimens from Tirnaskea, Tyrone. It is now in Jermyn Street Museum (No. 35576), and when figured again by Salter (op. cit., 1867, pl. 28, fig. 7) in his monograph was drawn with greater accuracy. Portlock (op. cit.) referred this specimen to *I. centrotus* Dalman, but this cannot be accepted. The shell is preserved over the greater part of the pygidium and shows small circular pits irregularly scattered amongst minute punctæ. The fascia is exposed all round the edges owing to the breaking away of the upper carapace, and it widens posteriorly, for its inner edge is formed by two gently concave curves meeting behind in the middle in a blunt cusp; the outer half of the fascia is convex, not flattened as in the Sholeshook specimen, though it becomes flattened at the lateral anterior angles, but the inner part is similarly concave and reflected closely beneath the upper carapace. There is thus a slight difference in its form from that of the Sholeshook specimen No. 24555, ascribed by Salter to *I. bowmanni* and mounted with the figured specimen No. 24553. The concentric lines on the outer part of the fascia of this Tirnaskea specimen are closer together than those on the inner part; nearly all are continuous except those on the median cusp where they are wider apart, broken, and very few (2–3 only) in number. Closely similar examples of pygidia having a well-marked convex outer part of the fascia and a concave inner part with a median cusp on the inner edge separating two concave curves are figured by Holm [3] from Stage F and named *I. linnarssoni.* Warburg [4] has rightly separated off from *I. linnarssoni* certain pygidia which Holm termed var. *avus*, for they have the inner curved margin of the fascia divided into three parts by a pair of cusps projecting inwards, instead of two parts with a single cusp.

The imperfect pygidium No. 24554 in the Jermyn Street Museum, which is labelled from Sholeshook and considered to be the original of one of Salter's figures (*Mon. Brit. Trilob.*, pl. 28, fig. 9) of *I. bowmanni*, is preserved in a dark grey irregular fissile limestone like that of the other Sholeshook specimens of pygidia. But it is completely different in every character from that (No. 35576) (op. cit., 1867, pl. 28, fig. 7) from Tirnaskea which has been just described. It is transversely semi-circular in shape, nearly twice as wide as long, has a fairly well-defined short triangular axis about two-fifths the length of the pygidium and with distinctly independent convexity; the convergent axial furrows, though shallow and weak, are clearly indicated nearly to the tip of the axis; the pleural lobes are wider than the axis; the fulcrum is at about one-third their width, and there is no marked oblique truncation of the outer lateral angles, but there is a strong flattened elongated triangular facet with a sharp raised ridge and groove behind it; the surface is densely pitted with rather coarse circular pits. In all these respects it differs from the pygidium from Tirnaskea (No. 35576) above described, though Salter referred it to the same species, and indeed it more resembles in shape *I. portlocki* Salter, but has not the strongly truncated lateral angles of this species as described in those examples from the Craighead Limestone of Girvan.[1] (These pygidia are now considered not to belong to *I. portlocki* but to a distinct species.) We may best compare this specimen, No. 24554, with Holm's species and variety, *I. angustifrons* var. *depressa*,[2] from Stage F2 of the Baltic Ordovician.

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[1] Salter, op. cit., 1867, pl. xxviii, fig. 9.

[2] Portlock, *Rep. Geol. Londond.*, 1843, pl. x, fig. 4.

[3] Holm, *Rev. Ostbalt. Silur. Trilob.*, iii, 1886 (*Mem. Acad. Imper. Sc. St. Petersb.*, **7**, xxxiii, No. 8), 146, t. x, figs. 20–2.

[4] Warburg, op. cit., 1925, 117, pl. ii, figs. 14–18.

The specimen (No. 35575) from Tirnaskea which Portlock [3] also figured as *I. centrotus* Dalm., but which Salter [4] in his monograph considered to be a young individual of *I. bowmanni*, consists of a nearly perfect trilobite with cranidium, thorax, and pygidium complete, but the free cheeks are missing. It is quite different from the types of *I. bowmanni* from Sholeshook and must be removed to another and new species. The cranidium is subquadrate and only slightly convex; there is a low narrow median ridge running along the middle of the glabella and pre-glabellar area to the front margin; the glabella is subconical, having decidedly convergent strong axial furrows which are expanded at their front ends, and it is more than one-third the length of the head-shield, and about twice as wide at its base as the fixed cheeks. The eyes are large, quite three-fourths the length of the glabella and situated far back close to the posterior margin; the anterior branches of the facial suture are slightly arched outwards but subparallel. The surface of the cranidium is rather closely pitted. There is no neck-furrow or occipital segment, but the fixed cheeks are slightly swollen at their inner angles, and the whole posterior edge of the cranidium is somewhat suddenly arched down.

The thorax has nine segments; the axis is conical, with deeply marked straight axial furrows converging rather rapidly behind; the anterior pleurae have the fulcrum at less than one-third the width of the axis, but its position moves outwards until on the last pleurae it is situated at quite two-thirds to three-fourths the width of the axis, which has here narrowed to about two-thirds its anterior width. The inner portion of the pleurae is horizontal and flat, and the portion outside the fulcrum is bent back sharply at about 45 degrees.

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[1] Reed, *Lr. Pal. Trilob. Girvan*, ii, 67, pl. ix, figs. 14–16.

[2] Holm, op. cit., 133, t. viii, figs. 14–22.

[3] Portlock, op. cit., pl. x, fig. 5.

[4] Salter, op. cit., 1848, pl. viii, fig. 8; and op. cit., 1867, pl. xxviii, fig. 8.

The pygidium is transversely semi-circular, about twice as broad as long and very gently convex; the axis has a weak independent convexity, especially near the front edge of the pygidium and is faintly defined as triangular by weak convergent axial furrows; it is about half the length of the pygidium and one-third its width; the lateral angles of the pygidium are truncated at about 45 degrees, the fulcrum being situated at about half the width of the pleural lobes and at about three-fourths the width of the axis; there is a short raised ridge behind the articulating facet on the truncated angles and a shallow groove behind it; a regular concentric line shows on the surface joining the fulcrum on opposite sides and indicating the inner edge of a broad fascia of uniform width equal to about half the length of the pygidium; there is also a doubtful trace of a narrow marginal rim. The surface of the pygidium seems to have been densely pitted.

Since there can be but little doubt that this specimen belongs to an entirely distinct species the name *tyronensis* may be suggested for it. It is apparently much like the trilobite termed *I.* cf. *oculosus* Holm, as figured by the present author from Ardmillan,[1] but in all the characters of the cranidium, and especially in the pygidium, it comes closest to *I. schmidti* Nieszk., as figured and described by Holm [2] from Stage C of the Baltic Ordovician.

The specimen of a head-shield (No. 35578) from Desertcreight, which was figured and described by Salter in his Monograph [3] as "a variety of *I. bowmanni* with longer and more connivent head-furrows" may be compared with the species *I. rosenbergi* Eichw. ?, as described and figured by McCoy [4] and Salter [5] from the Coniston Limestone. The relatively long glabella which is nearly half the length of the head-shield, the small eyes more than twice their length from the posterior margin, the course of the facial sutures, the general outline and convexity of the head-shield and the ornamentation of its surface which can be obscurely seen in some parts are features which strongly support this comparison. But as Salter suspected and as Holm [6] subsequently proved, this British form is quite distinct from Eichwald's species, and the name *Marshalli* which Salter proposed and Holm adopted must be used for it.

In conclusion the above described specimens which form the principal material on which Salter established his species *I. bowmanni* are thus seen to exhibit different characters which are quite sufficient to separate off some of them from the type of the species, and if we compare the dimensions here given of the several specimens we shall observe that, allowing for difference in age as indicated by size, the proportions of the various parts strongly support this conclusion.

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[1] Reed, op. cit., 71, pl. x, fig. 9.

[2] Holm, op. cit., 107, t. v, figs. 1–20.

[3] Salter, op. cit., 1867, pl. xxviii, fig. 11.

[4] McCoy, *Syn. Pal. Foss. Woodw. Mus.*, 1852, App. A, pl. 1 G, figs. 33–5 (*I. murchisoni*).

[5] Salter, op. cit., 1867, p. 199, pl. xxix, figs. 2–6.

[6] Holm, op. cit., 1886, p. 125.

DIMENSIONS OF SPECIMENS.

No. 24553. *Mem. Geol. Surv.*, ii, pt. i, pl. viii, fig. 1; *Mon. Brit. Trilob.*, pl. xxviii, fig. 12. *Illaenus bowmanni* Salt. (the type of the species).

	mm.
Length of head-shield	45
Width of cranidium between eyes	c. 64
Length of glabella	17
Width of glabella at narrowest part	28
,, ,, ,, ,, base	31
,, ,, fixed cheek at eye	16

No. 35576. *Mem. Geol. Surv.*, ii, pt. i, pl. viii, fig. 2; *Mon. Brit. Trilob.*, pl. xxviii, fig. 7. *Illaenus linnarssoni* Holm (restr.).

	mm.
Length of thorax	16·0
Width of thorax	40·0
,, ,, axis at front end	18·5
,, ,, ,, ,, posterior end	16·5
Length of pygidium	29·0
Width of pygidium	38·0
,, ,, axis of pygidium	16·5

No. 35575. Portlock, *Geol. Londond.*, pl. x, fig. 5; *Mem. Geol. Surv.*, ii, pt. i, pl. viii, fig. 3; *Mon. Brit. Trilob.*, pl. xxviii, fig. 8. *Illaenus tyronensis* nom. prop.

	mm.
Total length of trilobite	17·0
Length of head-shield	8·0
Width of cranidium between eyes	10·5
Length of pygidium	6·5
Width of pygidium	11·5

No. 24554. *Mon. Brit. Trilob.*, pl. xxviii, fig. 9. *Illaenus* cf. *angustifrons* Holm, var. *depressa*.

	mm.
Length of pygidium	9·0
Width of pygidium	c. 17·0
,, ,, axis	6·0

No. 35578. *Mon. Brit. Trilob.*, pl. xxviii, fig. 11. *Illaenus marshalli* Salter.

	mm.
Length of head-shield	24·0
Width of cranidium between eyes	33·5
Length of glabella	11·0
Width of glabella at base	15·0

No. 24555. Pygidium (not figured), from Sholeshook. (? *Illaenus bowmanni.*)

	mm.
Length	c. 23
Width	c. 31
„ of axis	13
„ „ fascia behind	c. 8

No. 24557. Pygidium (external impression) not figured, from Sholeshook. (? *Illaenus bowmanni.*)

	mm.
Length	33
Width (estimated)	c. 43

All the above-figured specimens come from Ordovician beds, though they belong to several species and only one positively to *I. bowmanni.*

But Salter went even further and included under this specific name even several specimens from Silurian beds, none of which agree with the type, and they must be regarded as distinct. Thus he figured [1] in his monograph as *I. bowmanni* an imperfect cranidium (No. 35320) from the "May Hill Sandstone of Norbury"; but it is labelled in the Jermyn Street Museum as from "Hope Quarry, Chirbury, Shropshire, Upper Llandovery". Dr. Stubblefield informs me that this locality is undoubtedly Llandovery, and is the type locality for *Leptostrophia compressa* (Sow.) yielding also *Pentamerus oblongus.* Dr. Whittard, who has also examined this specimen, writes to me that he is "almost convinced that it comes from the region of Hope Quarry which is mainly on the Pentamerus beds of the Valentian", and that none of his own specimens from the Valentian of Shropshire are referable to *I. bowmanni.* We cannot anyhow refer it to the same species as the Sholeshook type, from which it differs in its strongly hemispherical and inflated contour, larger eyes, and the strong outward arching of the anterior branches of the facial sutures. Salter's figure is not entirely satisfactory, for the axial furrow on the left side of the glabella is not so sigmoidal as he represents nor does it converge inwards, for it is nearly straight and runs at right angles to the posterior edge. The posterior branch of the facial suture is short, but bends out sharply behind the eye so as to cut the posterior margin at a very acute angle at a distance from the axial furrow equal to about two-thirds the basal width of the glabella. The eye lobe is unfortunately broken off, but it seems to have been semi-circular and much larger than in *I. bowmanni* from Sholeshook and less than its own length from the posterior edge. The fixed cheek is swollen towards the eye, but with the rest of the head-shield bends down sharply in front of it. On the free cheek there is a strong rounded pleuro-occipital furrow widening laterally, and across the base of the glabella a very narrow band-like meso-occipital ring. The surface is covered with small circular pits, but this is of no value for it is a feature in many species. The length of this cranidium is 21 mm. and its basal width between the points of section of the facial sutures is about 24 mm.; the glabella is 8 mm. long and its basal width about 10 mm.

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[1] Salter, op. cit., 1867, pl. xxviii, fig. 6.

Unfortunately the whole right cheek and part of the cranidium is broken away, and on account of the imperfection of the specimen we cannot satisfactorily institute a close comparison with any described species. But it much resembles one from the Upper Llandovery of Penkill, Girvan (No. 32976) in the Jermyn Street Museum labelled *I. nexilis* Salter (though certainly not that species), and it is possibly the same as the head-shield from Mulloch figured mistakenly by Salter [1] as *I. bowmanni*, but recognized by the present author [2] in 1906 as not referable to this species; it may possibly be allied to the unnamed variety of *I. aemulus* Salter, which has been described from the Llandovery of Girvan,[3] but there is no transverse lineation visible on the surface of the head-shield, and it is too imperfectly known to associate it positively with any British species.

There are also some other early figured specimens of *Illaenus* which have been attributed to *I. bowmanni* which must be mentioned. Thus there is the fine specimen in the Sedgwick Museum of a complete trilobite from Llanwddyn which McCoy figured as *I. centrotus* [4] and Salter [5] subsequently as *I. bowmanni*. It consists of a perfect external hollow impression of a whole trilobite (with the exception of the lateral margin of the head-shield and of the pygidium) and the natural cast of the pygidium and part of the thorax of the same specimen, showing also the impression of the doublure and epistome of the head-shield, but the rest of the specimen is missing. McCoy's and Salter's figures were drawn from a gutta-percha cast of the impression. The cranidium agrees closely with the Sholeshook type, No. 24553, allowing for the distortion of the latter, for the very wide short glabella, sub-parallel axial furrows and relatively narrow fixed cheeks are similar. The base of the right free cheek is partly preserved and shows that the eye was elevated and its base surrounded by a wide rounded furrow; the genal angle is broadly rounded and the basal width of the free cheek does not seem to be greater than that of the fixed cheek. The pitting of the head-shield seems to be similar to that of the Sholeshook form. In the case of the thorax some crushing has taken place, but the great width of the axis and its very slow rate of tapering are marked features, the pleural lobes being only about half its width, but the inner horizontal portion of these lobes increases in width posteriorly. The extra-fulcral portions of the pleurae are not well preserved, but are longer than the inner portion and are sharply and suddenly bent down and slightly back at the fulcrum, curving back to bluntly pointed but not truncated ends, as can be seen in a few places, though the tips of the pleurae are mostly broken off.

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[1] Salter, op. cit., 1867, pl. xxx, fig. 6. (This specimen cannot be traced.)

[2] Reed, op. cit., 1904, p. 59.

[3] Ibid., 55, pl. viii, figs. 6–11.

[4] McCoy, *Syn. Brit. Pal. Foss. Woodw. Mus.*, Appendix A, 1852, iv, pl. 1 E, fig. 19.

[5] Salter, op. cit., 1867, pl. xxviii, fig. 10.

The pygidium is clearly semi-elliptical in shape and not transversely semi-circular; it has a gentle convexity from side to side and from back to front. The axis is rather more than one-third the width, and projects on the margin, being defined by rather deep indentations, but except near the margin it has no independent convexity or definition though it forms the highest part of the gently convex surface of the pygidium. The fulcrum on the lateral lobe is placed at about half the width of the axis and is strongly angular and slightly raised with a weak groove behind it; the outer lateral angle is strongly truncated at about 45 to 60 degrees, but this part of the specimen is rather distorted. The fascia which is exposed in the natural cast has a rather narrow outer convex portion and a much broader concave inner portion extending back inwards more than one-third the length of the pygidium and closely oppressed to the carapace; there is some indication that its inner edge was formed by two gently concave curves uniting in the middle, but this union is mostly hidden by the broken edges of the carapace; the concentric lines on the outer convex portion of the fascia are closer together than those on the inner broader part, and a weak narrow median groove crosses the whole fascia. The surface of the pygidium appears to have been covered with small pits scattered amongst dense minute punctae. The whole pygidium seems to be practically identical in character with that figured by Portlock and Salter[1] (No. 35576) from Tirnaskea, and described above as probably referable to *I. linnarssoni* Holm.

The cephalic doublure of the same specimen is well preserved as a sharp impression and is clearly seen on the left side where also the lower surface of the free cheek is partly preserved. The latter shows a thickened edge with the inner portion of the cheek crossed by short parallel sharp fine lines set at right angles to the margin. The rest of the doublure bears the usual strong lamellose concentric lines on its surface, about 12–14 in number. The epistome is broadly subfusiform, about twice as wide from side to side as from back to front; the anterior edge has a very slight curvature; the posterior edge is more strongly arched, but does not project in the middle; the sides are truncated at 45 to 60 degrees to the anterior edge, converging posteriorly, and the whole surface is crossed by 12–14 strong continuous subequidistant lamellose lines concentric to the anterior and posterior edges. The general characters of this epistome and doublure also resemble those of *I. linnarssoni.*[1]

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[1] Salter, op. cit., 1848, pl. viii, fig. 2.

DIMENSIONS.

	mm.
Length of whole trilobite	c. 78
,, ,, head-shield	c. 35
Width of head-shield at base	c. 44
Length of glabella	16
Width of glabella at base	19
Length of thorax	c. 13
Width of axis of thorax at front end	19
,, ,, ,, ,, ,, ,, posterior end	15
Length of pygidium	31
Width of pygidium	c. 39
,, ,, axis at front end	15
,, ,, epistome from side to side	23
Length of epistome from back to front	11

The other and rather larger example from Llanwyddyn in the Sedgwick Museum, figured by McCoy[2] as *I. centrotus*, was referred by Salter to *I. bowmanni*, but we may doubt if it belongs to the same species as the previous one just described and figured from Llanwddyn. For the head-shield and pygidium are much more transverse, and this does not seem wholly due to crushing or distortion. The specimen consists of an enrolled individual with the head-shield and pygidium pressed together; part of the doublure of the head-shield shows behind the posterior edge of the pygidium and the marginal part of the head-shield is crushed and bent under along a subconcentric crack, so that from above it looks too transverse. Only seven rings of the thorax are visible, the missing two being probably squeezed under the edge of the pygidium. The specimen is not in a very good state of preservation, but is important as showing the three parts, head, thorax, and pygidium, attached. and the left free cheek in position and nearly perfect. This free cheek is long and narrow with a very short posterior edge and widely rounded genal angle, the whole outer and posterior margin from the facial suture forming a continuous curve flattening anteriorly. As far as measurements are possible it is only about half or less than half the basal width of the fixed cheek. The characters and proportions of the glabella and fixed cheeks seem to be much like those of the typical *I. bowmanni* from Sholeshook and thus do not agree with those in the other Llanwddyn specimen. But there is no distinct neck-ring and the glabella narrows slightly anteriorly. The pygidium differs considerably, being transversely semicircular, though this may be due to distortion by crushing, but as it is practically perfect and its edges (except the anterior margin) are complete, its characters are of special value. Its length is to its width more than 2 : 3 instead of about 3 : 4; its lateral angles are more obliquely truncated and somewhat arched, forming an obtuse angle of 150 degrees with the inner part of the anterior edge of the pygidium ; the fulcrum is distant from the axial furrow about half the width of the axis. The fascia is very wide, has no definitely convex outer portion, but is gently concave from the outer edge inwards, is closely appressed to the carapace and widens behind, but whether the inner edge is formed by a pair of shallow concave curves meeting in the centre at a cusp as in *I. linnarssoni* is not determinable owing to its state of preservation. The fascia extends inwards fully half the length of the pygidium and bears a few rather widely spaced equidistant concentric lines, but near the outer margin they are more closely placed. The surface of the pygidium has the usual minute dense punctation with some small circular pits scattered about irregularly. There are no traces of terrace-lines on it as in Salter's specimen (No. 24557) of *I. bowmanni* from Sholeshook.

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[1] Warburg, op. cit., 117, pl. ii, figs. 14–18.

[2] McCoy, op. cit., pl. 1 E, fig. 19*a*.

DIMENSIONS.

	mm.
Length of head-shield . . .	c. 44
Width of cranidium between eyes .	c. 63
,, ,, glabella at base . .	27
Length of glabella . . .	17
Width of fixed cheek at base . .	14
,, ,, free cheek at level of eye	c. 7
Length of pygidium . . .	c. 38
Width of pygidium . . .	62
,, ,, axis	c. 25

This specimen in shape and proportions of its different parts agrees more closely with a Girvan form from the Drummuck Beds of Lady Burn which the author is describing elsewhere as *I. fluvialis* ; the chief difference being in the apparent absence of an outer convex portion to the caudal fascia, but this may be due to the dorso-ventral flattening of the Llanwddyn specimen by pressure from which it has clearly suffered and by which such a feature would be almost or quite obliterated. We may therefore with much probability ascribe it to this species.

There are many more or less imperfect specimens of head-shields of *I. bowmanni* in the Sedgwick Museum collected by Messrs. Marr and Roberts and by Mr. Turnbull from the type-locality Sholeshook which are indistinguishable from those from that locality figured by Salter and above described, but no complete individual or pygidia which can be positively assigned to this species. Fortunately, there is one complete individual of *I. Davisi* Salt, from Sholeshook (No. 1097, Sedgw. Mus.) which enables us to distinguish the pygidia. The fascia on this species is of uniform width all round, for there is no posterior widening and no median cusp or median concave curve ; it is also gently convex and only about one-fifth or one-sixth the total length of the pygidium, and the concentric lines are regular, equidistant, and continuous. It is by the fascia of the pygidium rather than by the head-shields that we seem best to be able to distinguish these various species of *Illaenus* and we can recognize three main types in the genus :—

(1) Fascia widening behind ; inner edge formed by two concave curves meeting in a median cusp ;

(2) Fascia widening behind ; inner edge formed by three concave curves, forming a pair of cusps ;

(3) Fascia of uniform width ; inner edge formed by one regular curve concentric with margin of pygidium.

Summing up the evidence from the above-described specimens we are led to limit the application of the specific name *I. bowmanni* to the Sholeshook specimens (Nos. 24553, 24556) of cranidia figured by Salter, but we may probably refer to the same species one, at any rate, of the pygidia (Nos. 24555, 24557) from the same locality which were presumably used by him in drawing up his original diagnosis. As for the others we have been led to conclude that the small pygidium (No. 24554) from that locality is distinct and may be better compared with *I. angustifrons* var. *depressa* Holm.

The Tyrone specimen of thorax and pygidium, No. 35576, should be referred to *I. linnarssoni* Holm.

The complete Tyrone trilobite No. 35575 is a new species, for which the name *tyronensis* is proposed.

The head-shield No. 35578 from Desertcreight is probably referable to *I. marshalli* Salter.

The Silurian specimen No. 35320 from Chirbury is not specifically determinable, and probably the missing specimen from the Llandovery of Mulloch figured by Salter is referable to *I. aemulus*, while one of McCoy's specimens of *I. centrotus* from Llanwddyn may be referred to *I. linnarssoni* ; but the other from this locality probably belongs to the same species as that from the Drummuck beds of Girvan to which the author has given the M.S. name *fluvialis*.

REVIEWS.

GALLOWAY: THE SPELL OF ITS HILLS AND GLENS. By ANDREW McCORMICK. To which is added THE GEOLOGY OF THE MERRICK REGION. By R. J. A. ECKFORD. 8vo, pp. 283, with 36 illustrations and map. Glasgow, 1932.

SIR HERBERT MAXWELL, who supplies a brief Introduction, likens this book to a tract of Silurian strata broken and displaced by intrusions. A closer parallel perhaps would be such a country as Central Mull, where the intrusions occupy nearly all the ground. The description of the Galloway hills and glens is interwoven with a running account of the author's adventures, not always very exciting, and with innumerable stories, good and less good. Of more interest is the admixture of local history and legend, introducing a crowd of Gallovidian worthies, from Robert Bruce to Mr. Crockett.

The final chapter, by Mr. Eckford, gives a good summary account of the geology of the district, addressed to the general reader. A useful appendix is a list of walks through the hill country, with a map on which the routes are marked. The book is illustrated by a number of admirable reproductions of photographs.

A. H.

THE ITALIAN EXPEDITION TO THE HIMALAYA, KARAKORAM, AND EASTERN TURKESTAN (1913–14). By FILIPPO DE FILIPPI, with chapters by G. DAINELLI and J. A. SPRANGER. pp. xvi + 528, with two coloured plates, four maps in colour, 15 panoramas, and more than 300 photographs in the text. London: Edward Arnold and Co., 1932. Price 50*s*. net.

THIS fine and richly illustrated volume contains the narrative of Dr. de Filippi's famous expedition. It is written for the general reader, and the geologist must not look for geological details, but he is sure to be interested in the numerous panoramic and other views showing the character of the country passed through. The full reports on the scientific work of the expedition occupy several volumes which are being published in Italy. They are now nearly completed, and accordingly Dr. Filippi has been able to add to this English edition of the narrative a useful synopsis of the results.

One of the primary objects of the expedition was the determination of gravity, for which a much more elaborate equipment is required than is usually carried on such expeditions. The observations which were made confirm the general conclusion of the Survey of India that there is an excess of gravity in the Himalaya and a defect both to the north and to the south of it.

From his examination of the Quaternary deposits, Dainelli concludes that there were two great expansions of the ice and at least four minor ones.

P. L.

STREAM SCULPTURE ON THE ATLANTIC SLOPE. By DOUGLAS JOHNSON. pp. xxii + 142. New York: Columbia University Press, 1931; London: Milford. Price 22*s*. net.

THIS book, in conjunction with the papers by W. M. Davis upon the same subject, offers a striking illustration of the dangers inherent in the application of deductive methods to an inexact science; and the foreword, by Professor Davis himself, is an admirable example of the open-mindedness which is essential to minimize or avoid those dangers.

Professor Johnson is a disciple of Davis and uses his methods with a skill almost equal to that of his master, but he comes to very different conclusions. Davis is satisfied that Johnson's interpretation of the Appalachian river-system is better than his own; but at the conclusion of his paper on the rivers of Pennsylvania he had said: "I feel that the history of our rivers is not yet settled," and he does not now think that Johnson's results should be taken as absolutely final.

The danger of the deductive method is like that which besets the youthful botanist in using a dichotomous table to identify a plant that he does not know. If he once takes the wrong branch he may obtain an extraordinary result; but he is not usually convinced by it. The geomorphologist who makes one false step is much more likely to be deceived; and, if Johnson's interpretation is correct, Davis's first step was his false one.

The river-system of Pennsylvania is very unnatural-looking. The greater rivers rise on the western side of the Appalachians and flow south-eastwards through the mountains to the sea. Davis supposed that the drainage was formerly towards the north-west. The depression of a central zone, in which the Newark beds were deposited, led to a reversal of the middle segments of the main consequent streams, and capture by rivers flowing down the Atlantic slope completed the process. He felt that this reversal was the least satisfactory part of his story, but the alternatives that suggested themselves to him were less satisfactory still.

Johnson gets over the difficulty by wiping out the Appalachians before the rivers begin. The range was completely worn down to a peneplain, which he calls the Fall Zone peneplain. In Cretaceous times the sea spread over it and buried the worn-down folds beneath a layer of sediment. There was then an uplift and an arching of the peneplain with its sedimentary cover, and upon this cover arose rivers flowing to the south-east, quite independent of the Appalachian structure beneath. It was a case of superimposed drainage. We cannot here follow the subsequent development of the system, but it should be noted that the well-known Schooley peneplain truncates the arch of the Fall Zone peneplain and must be of later date.

Johnson's explanation is very much simpler than that of Davis, and consequently is more satisfying to the mind; but simplicity is not a proof of truth to nature, and for the evidence the reader must refer to Johnson's book. P. L.

PRELIMINARY NOTE ON DEVONIAN STEGOCEPHALIANS FROM EAST GREENLAND. By G. SÄVE-SÖDERBERGH. *Meddelelser om Grønland*, Bd. 94, Nr. 7, 1932. pp. 1–105, 22 text-figures, 22 pls. Price, Kr. 8·00.

THE oldest amphibia hitherto known are the Embolomerous forms of the Carboniferous, and in the Croonian Lecture for 1924 Professor Watson suggested that they arose from a fish ancestral also both to the Osteolepids (from which it differed only in the absence of certain adaptive features) and the Dipnoans, and that the actual origin of the group took place no later than Devonian times and possibly earlier. The characters of this hypothetical fish ancestor can to some extent be deduced by a backward extension of the evolutionary trends of the *Stereospondyli*, *Rachitomi*, and *Embolomeri*. Now, by one of the more fortunate of recent discoveries, a series of Devonian amphibia has come to light through the work of the Danish East Greenland Expedition of 1931, and a preliminary report on the dermal bones of the skull is given by Dr. Söderbergh in the present monograph. The Upper Devonian age of this material has been established by the fish fauna of the same fossiliferous localities, which has been in part described by Professor Stensiö. That this new amphibian fauna should be found to constitute a separate group not lying on the main line of descent of the later Stegocephalians may seem a little disappointing, but it represents a type whose organization is of the highest importance and it gives, moreover, a somewhat greater precision to our chronology. Dr. Söderbergh places the fish ancestors of the Crossopterygians, Dipnoi, and Stegocephalians in the Lower Devonian or Silurian.

The forms here described are referred to two new genera, *Ichthyostega* and *Ichthyostegopsis*, constituting the family *Ichthyostegidae*, for which the author proposes a new Order. From the diagnosis of the family, we may note particularly the presence of an incomplete median suture to the skull roof (i.e. an unpaired parieto-extrascapular posteriorly and rostro-interrostral anteriorly), of small pre-operculars (probably present in all) and of a premaxilla fused with the lateral rostrals to form a rostro-premaxillary, of which the premaxillary component is entirely confined to the ventral surface. The external nares must have been situated on the ventral side of the skull, opening ventro-laterally between the anterior ends of the maxillaries and the posterior ends of the tooth-bearing parts of the rostro-premaxillaries. The palate is well ossified, and the palatal vacuities small. Two rows of teeth occur in the mandible.

In the interpretation and naming of the various dermal bones of the skull roof, their relations to the sensory canals (lateral lines) are discussed as fully as possible, and comparison is made with the skulls of the Crossopterygians, Dipnoans, and later Stegocephalians. The supposition is inevitable, concludes the author, that the Ichthyostegids and primitive Crossopterygians had a common ancestor from which neither has departed to any great extent, and while we cannot enter into detail in a short abstract, the general fact emerges that this ancestral form must have possessed very numerous dermal bones (including several rostral elements, two pairs of frontals and of parietals, and five extrascapulars), which, by their different combinations, have produced the skull patterns of the various later types. In making a comparison with the Dipnoan skull, a new interpretation of the cranial roof of *Dipterus* is employed, based on unpublished work of Professor Stensiö, which again shows five extrascapular elements and a subdivision of the frontals and parietals. *Dipterus* is, in some respects, more nearly related to the Ichthyostegids than are the Crossopterygians.

Turning to a comparison with the later Stegocephalians, we note at once what is probably the most important difference, namely the position of the external nares. Those of the Stegocephalians are the displaced homologues of the Ichthyostegid external nares, which, like those of the Dipnoi, are considered to be homologous with the *posterior* external nares of primitive Crossopterygians. The median suture of the skull roof is complete in the later Stegocephalians and the unpaired parieto-extrascapular and rostro-interrostral have disappeared, as have also the anterior antorbital and the independent pre-opercular. The palate is essentially similar.

Lastly, certain characters of some of the *Embolomeri* are noted which are considered by Professor Watson to be primitive and directly inherited from a fish ancestor and yet are not found in the *Ichthyostegidae*. Among these are mentioned the loose attachment of the squamosal to the inter-temporal and supra-temporal, the presence of a deep otic notch, and the existence of a free inter-temporal bone. On the view that these features are truly primitive, it appears that the *Ichthyostegidae* and the *Embolomeri* are to some extent parallel groups, the Ichthyostegids retaining a larger number of primitive characters.

Dr. Säve-Söderbergh is to be congratulated on the work he has already accomplished ; the promised account of the endocranium of this new Order may determine some of the points left undecided, and will certainly be eagerly awaited by all interested in the origin of the Tetrapods.

O. M. B. B.

CORRESPONDENCE.

THE GENESIS OF LEUCITE AND MELILITE ROCKS.

SIR,—In his letter to the GEOLOGICAL MAGAZINE for December, 1932, Professor S. J. Shand confesses inability to believe the hypothesis I have proposed for the origin of the leucite- and melilite-bearing rocks of the volcanic districts near Ruwenzori (*Quart. Journ. Geol. Soc.*, 1932, pp. 370–442).

It would seem that his main objection is less an impeachment of the differentiation-processes outlined in the hypothesis than a criticism of an assumption of his own for which there is no warrant in the paper cited. Professor Shand identifies my hypothetical parental peridotite magma with the peridotite zone " generally thought to begin some 40 miles beneath the surface and to extend down to a depth of about a thousand miles ". If the hypothesis necessarily implied acceptance of this correlation, I should disbelieve it myself, if only because the processes of differentiation that I suggested could never take place in a world-wide layer of magma ; high viscosity and sluggishness of movement would prevent any effective separation of phases.

In the article on " The Origin of Igneous Rocks ", which precedes Professor Shand's letter, brief reference is made to the conditions I had in mind. I consider the parent peridotite magma to be largely derived from the re-fusion of the crystalline uppermost part of the Lower Layer. Wherever such magma locally works its way up into the crust and comes to occupy a laterally confined position, both differentiation and extrusion tend to be favoured. The magma—parent or residual—may be forced towards the surface under the external stimulus of hydrostatic or tectonic pressure, or it may become so highly charged with volatiles in consequence of crystallization that the internal " shouldering " pressure reaches bursting point, fractures the crust, and ultimately leads to explosive perforation of the overlying rocks. To this final effect all three sources of pressure may contribute, simultaneously or in successive stages.

In the article to which reference is made above I have given reasons for believing that peridotite magma from the base of the crust cannot be expected, except locally and in relatively small masses, to approach or reach the surface. I had no intention of discussing such highly speculative matters in the Uganda paper, but I hope that these general considerations will serve to show that the localized occurrence of potash-rich basic rocks, which Professor Shand rightly stresses, is in accordance with my own postulates and is not inconsistent with the hypothesis. The origin of these rock-types seems to me to be necessarily conditioned by local circumstances, thermal and tectonic.

The hypothesis under discussion is not based on speculations about the earth's interior, but on (*a*) the actual presence of enstatite phenocrysts in melilite-basalt and of eclogite inclusions in kimberlite ; (*b*) the heteromorphic relationship between olivine-rich olivineleucitite and kimberlite ; (*c*) the absence of the slightest evidence to suggest that magmas of granitic or basaltic composition played a part in the production of the volcanic rocks described ; and (*d*) the similarity of the assemblages of minor constituents found in these rocks and in mica-peridotites. From such field, petrographical, and geochemical evidence it is inferred that the parental magma was probably peridotitic. The operation of high pressure is inferred from the highly explosive character and drilling power of the magmas erupted and from the remarkable uplift of the Ruwenzori massif, which occurred not long before the volcanic outbursts.

Professor Shand questions the validity of evidence based on (*d*) the minor constituents, on the grounds that the quantities assigned to these constituents by analysts may not be reliable. He wonders if Dr. Harwood shares my faith. The letter that follows will, I hope, suffice to convert Professor Shand to a realization that the minor constituents may sometimes be of critical value in the attempt to solve problems of petrogenesis. Twenty-three years have elapsed since Hillebrand urged the need for more complete analyses (showing up to 29 constituents) and devised methods whereby any well-trained rock-analyst could carry them out successfully. In the hands of later workers, such as Washington, Goldschmidt, and Fersmann, the principles and methods of geochemistry have yielded a rich and growing harvest of results which should be familiar to all petrologists. As the value of such evidence is now being fully recognized by certain British workers, it is of the utmost importance that Professor Shand's strictures on analytical methods and reagents should be proved to be without serious foundation. It is surely unbelievable that the reagents used in various parts of the world should always happen to carry noteworthy quantities of strontium when leucitic rocks are being analysed, and yet remain nearly free from strontium when they are used for basalts or granites.

The evidence against the limestone-assimilation hypothesis in the neighbourhood of Ruwenzori may be briefly summarized as : (*a*) the absence of limestone at the surface and, as demonstrated by the ejected blocks, in depth ; and (*b*) the absence of any indications that either granitic or basaltic magma was available to react with any limestone there might have been. I am not impressed by Professor Shand's implication that ejected blocks of melanite-bearing pyroxenites and tremolite-bearing hornblendites (not amphibolites, as Professor Shand states) may provide indirect evidence of the present or former existence of limestone in depth. Even if melanite and tremolite indisputably implied limestone, which they do not, the difficulty of tracing the nature of the parent magma would still remain. It is worth remembering that kimberlite pipes carry blocks of limestone or dolomite where the regional geology affords evidence that they cut such formations, but that elsewhere, that is to say, in a majority of the known pipes, although limestone and dolomite inclusions are lacking, the kimberlite is there just the same.

On the evidence afforded by the alkali rocks that he has specially investigated, Professor Shand has made out a consistent and weighty case for limestone-assimilation. My own experience with alkali rocks has been in regions where there does not appear to have been any limestone to be assimilated, and I have therefore been constantly on the alert for clues pointing towards an alternative hypothesis. I see no reason, despite a prevalent opinion to the contrary, why alkali rocks should be formed by one kind of process and one only. Nature is not above the occasional perpetration of puns. I believe, however, that the Ca^{41} test will ultimately come to our rescue, and I shall not be surprised if both hypotheses prove to be applicable in their appropriate fields.

ARTHUR HOLMES.

SCIENCE LABORATORIES,
SOUTH ROAD, DURHAM.
14*th December*, 1932.

SIR, — In reply to the criticism made by Professor Shand (GEOLOGICAL MAGAZINE, December, 1932) as to the accuracy of the determinations of the minor constituents present in rocks, no chemist who has a practical knowledge of rock analysis would suggest for a moment that the figures given for these constituents in published analyses should invariably be accepted as absolutely correct, having regard to the complexity of the analysis and the liability to inevitable experimental error. The situation, is, however, not so bad as Professor Shand makes out. In the first place, all the minor constituents with the exception of strontia (determined in the main portion) are determined, not in portions of 0·5 gram or 1 gram of rock (which would be useless in most cases) but, in separate quantities of rock-powder each weighing from 2 to 5 grams. Hillebrand, in his well-known book on rock analysis, gives details of methods which permit of the detection and determination of zirconia and the rare earths when these are present to the extent of only ·02 to ·03 per cent, and the writer, in conjunction with one of his colleagues, has devised a method (shortly to be published) which allows of the determination in a rock of only ·01 of nickel oxide. Small amounts of fluorine can be determined by a colorimetric method, and the same applies to manganese and chromium, a lower limit of ·01 per cent being easily attainable in the two latter cases. Small amounts of chlorine, barium, and vanadium can also be determined satisfactorily, the two former by gravimetric methods and the latter volumetrically, although not less than 5 grams of rock must be used for the vanadium determination. The writer is not prepared to defend the accuracy of the strontium determination as at present carried out in rock analysis; in his opinion the results for this element are likely to be somewhat low in all cases, but this particular determination is now under investigation with a view to ascertaining the conditions necessary for the attainment of the greatest possible accuracy. The suggestion made by Professor Shand that the amounts of certain minor constituents reported in rock analyses may depend either upon the personal factor of the analyst himself or upon the particular reagents used, is disproved by the present instance. Simultaneously with the work on the Uganda rocks, the writer was engaged in carrying out another set of analyses (not yet published) on a series of metamorphic rocks from Egypt and the Sudan. Of the six rocks constituting the series, five showed no strontia at all, and the sixth a trace only, whilst three of the rocks showed no barium oxide, and the remainder amounts varying from ·01 to ·03 per cent. These analyses were carried out by the same methods, and with reagents drawn from the same stocks as those used for the Uganda rocks, whose content of barium and strontium oxides was relatively large. It may be pointed out here that the purity of the weighed sulphates of barium and strontium is tested by examination with the spectroscope in order to ascertain their practical freedom from calcium.

In conclusion the writer believes that the special significance of very small amounts of minor constituents does not lie in the absolute values of the figures obtained for these by analytical methods, but in their relative values. It is not for a moment disputed that an error of 25 per cent or even 50 per cent may in certain cases occur in the determination of some constituent present to the extent of only ·02 or ·04 per cent, but even so, a real distinction can be drawn, in his opinion, between these values and the occurrence of the particular element in " traces " only. It is on such differences, as well as on the occurrence of larger quantities, that geochemical theories should be based, as illustrated by the treatment of certain problems by Professor Holmes in the joint paper on the Uganda rocks (p. 422).

H. F. HARWOOD.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY.
7th December, 1932.

SIR,—In your correspondence of December, 1932, Professor Shand criticizing the paper by Drs. Holmes and Harwood on the volcanic rocks near Ruwenzori (*Quart. Journ. Geol. Soc.*, lxxxviii, 370) has suggested that the SrO found in so many of the rocks of Southern Rhodesia is " just as likely to be characteristic of a particular analyst or a particular batch of reagents as of the rocks themselves ". Professor Shand further states that, until minor constituents of rocks are determined in samples at least ten times as large as those ordinarily used in rock analyses, the results are more or less unreliable.

The suggestions tend to make the detailed analyses of rocks valueless, and are distinctly unfair to the chemists who are engaged on this branch of work.

The methods I have used for all rock analyses are those advocated by Washington and Hillebrand. The determination of strontium oxide has always been carried out according to Washington's method given on pages 179–180 in his book, *Manual of the Chemical Analysis of Rocks*, using a 2 gm. sample of rock which enables the accurate determination of 0·005 per cent SrO, and of course the analyses are carried out in duplicate. The reagents used are of the purest quality, and fresh supplies are obtained each year. Blank determinations are made with every new bottle, and always on the final ether-alcohol-sulphuric-acid-water portion. This, coupled with the fact that a notable amount of strontium in the chemical analyses of Southern Rhodesian rocks has been evident over a period of six years and has been confirmed by the spectroscope, disposes of the possibility of reagent contamination.

It can hardly be said that the personal factor enters into this determination, for the method is undoubtedly a simple one and according to Washington " there are no serious errors involved ".

E. GOLDING.

OFFICE OF THE GEOLOGICAL SURVEY,
SALISBURY, SOUTHERN RHODESIA.
10th January, 1933.

LATERITE.

SIR,—I write to endorse J. B. S.'s statement in his review of Dr. Fox's *Bauxite and Aluminous Laterite* in your December issue (p. 560) that " many would be grateful if Indian geologists would give us analyses of Buchanan's type rocks from the type localities that he visited in 1800 and described in 1807. They would throw light on the necessity of considering aluminium hydrate a characteristic ingredient."

They would throw light on other questions, too, especially if the analyses could be accompanied by lithological and stratigraphical descriptions together with proof either that Buchanan's laterite is forming at the present day or that it is not.

It appears from Mr. Lake's remarks on the paper by Messrs. Richards, Cammiade, and Burkitt in the GEOLOGICAL MAGAZINE for May, 1932, 205, that Buchanan's laterite is not forming in the drier climate of the Madras side.

The Imperial Bureau of Soil Science has recently published a valuable compendium on " Laterite and Lateritic Soils " (*Technical Communication* No. 24). It is evident that soil chemists are establishing a definite type of soil, mainly on chemical characteristics, which they are calling laterite, but whether it has any right to that name remains an open question.

H. B. MAUFE.

OFFICE OF THE GEOLOGICAL SURVEY,
SALISBURY, SOUTHERN RHODESIA.
3rd January, 1933.